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Hoba (South-West Africa), the largest known meteorite.

(With Plate I.)

By L. J. Spencer, M.A., Sc.D., F.R.S.
With chemical analyses by M. H. Hey, B.A., B.Sc.
Mineral Department, British Museum of Natural History.

[Read June 9, 1931.]

IN 1910 in volume 15 of this Magazine I was able to place on record some details respecting the 'Cullinan' diamond from South Africa, the largest crystal of diamond yet found. I have now been able to collect some information about the largest known meteorite. The facts concerning remarkable objects such as these are apt to become exaggerated and distorted, and it is well to place on record the true and accurate data while they can still be ascertained.

The scanty accounts so far published of the Hoba meteorite give the date of discovery as 'about twenty' or 'about ten years ago'. Its weight has been variously estimated at 40, 50, 60, 70, 87, and 100 tons, and the dimensions mentioned have ranged up to 8 metres.

The locality (fig. 1) where the mass still lies is close to the southern boundary of the Hoba-West farm (no. 322) in the Grootfontein district. It is 12 miles (by road 15 miles) west of the town of Grootfontein (meaning in Dutch, great spring). The mass has consequently, not inappropriately, been referred to as the Grootfontein meteorite. Its position is given approximately by latitude 19° 35′ S., longitude 17° 56′ E. It lies a couple of hundred yards on the east side from the rough side-road leading to Otjihaenene siding

on the railway from Grootfontein to Otavi, and only four kilometres from the narrow 2-foot gauge railway-line.

On the German map (1 : 400,000) issued in 1910 by the Survey Department in Berlin, and reproduced by the English Ordnance Survey in 1915, this farm is marked as Paviansfontein, but on the estate map of the South West Africa Company it appears as Hoba-West. The Afrikaans form is Hoba-Wes. The adjoining farm to the east is known as Hoba-Ost (the German form for Hoba-East), and the homesteads of both farms form a group of substantial buildings where the main road crosses the farm boundary. On some maps this is marked simply as Hoba.[1]

The exact date of the discovery of the mass I have not yet been able to ascertain, but it appears to have been late in 1920. Mr. Michael H. Hanssen the then occupier of the farm has since left. Dr. Paul Range, formerly Government Geologist of German South-West Africa, who had made a special study of the meteorites of the country,[2] informs me that the Hoba meteorite was certainly not known previous to the war of 1914–18. The earliest mention of the mass appears to be in a letter dated May 26, 1921, from the late Mr. T. Tönnesen, General Manager in Grootfontein of the South West Africa Company, to the London office, which I am permitted to quote. Accompanying this letter there is a photograph of the meteorite partly exposed in the pit dug round it.

> On the farm Hoba-West, about 20 kilometres to the west of Grootfontein, there is a meteorite, which is about 2·5 by 2·5 metres on the surface and may have a thickness of probably 2 metres (only 1 metre has been exposed). Accordingly the weight would be 87 tons, but it is safer to say 60 tons. The assay shows 81·29 % iron and 17·49 % nickel. The nickel content will probably amount to 10 tons. The stuff is very ductile, precluding blasting. We shall try a saw and eventually an oxy-acetylene flame.

Since all meteorites in South-West Africa are the property of the Government, nothing further was done in the way of mining for nickel.

In September 1921, Mr. M. H. Hanssen wrote from Hoba-West to the Director of Geological Survey of the Union of South Africa in Pretoria, giving the dimensions of the meteorite as over 3 yards by

[1] An incorrect form 'Hobart' is evidently due to the prevalent idea that foreign words must be pronounced as French, in the same way that all foreigners are 'Monsieur'.

[2] P. Range, Meteoriten aus Deutsch-Südwestafrika. Mitt. Deutsch. Schutzgebieten, 1913, vol. 26, pp. 341–343.

3 yards by 39 inches thick, and quoting the results of the assay made by the South West Africa Company.

The first published mention of the meteorite appears to be in Dr. G. T. Prior's 'Catalogue of Meteorites' (British Museum, 1923, p. 73). This was based on a verbal communication from Prof. Charles Palache, who visited the locality when on the Shaler Memorial Expedition from Harvard University to South Africa in

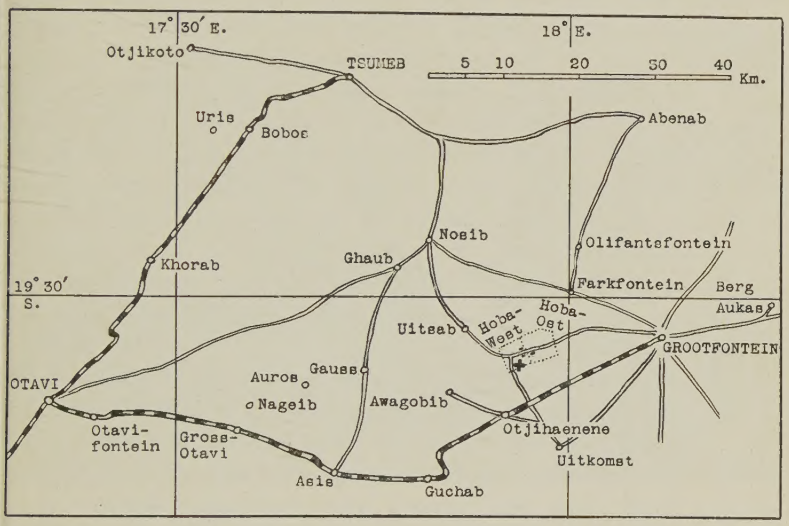


FIG. 1. Sketch-map (1 : 1,000,000) showing the position of the Hoba meteorite, Grootfontein district, South-West Africa,[1]

1922. Some further information in the 'Appendix to the Catalogue of Meteorites' (British Museum, 1927, p. 23) was supplied in 1926 by Dr. A. W. Rogers, the Director of the Geological Survey of the Union of South Africa. This was based on the letter of Mr. Hanssen mentioned above.

The next mention of the meteorite that I have been able to find is an anonymous note headed 'the largest meteors' in 'Science' of March 22, 1929 (New York, vol. 69, p. xii), which was reprinted in the American Mineralogist, 1929, vol. 14, p. 201.

A seventy-ton meteor [i.e. meteorite] is reported to have been found at Otjihaene [i.e. Otjihaenene], near the head of the Grootfontein railway in the northeastern part of Southwest Africa, imbedded in soft limestone. Its approximate

[1] The opportunity has been taken to mark on this map the localities of vanadium minerals represented in the British Museum collection.

size is ten by ten by four feet. Though this is said to be the largest meteor actually discovered in the world, it is probably dwarfed by the one which many years ago caused the famous Meteor Crater in Arizona. . . .

In a special number of the 'Zeitschrift für praktische Geologie' issued in June 1929 on the occasion of the XVth Session of the International Geological Congress in South Africa, Prof. H. Schneiderhöhn[1] gave a brief account of the Hoba meteorite. This was based on information supplied by Mr. A. Stahl and is accompanied by a photograph taken by Mr. F. W. Kegel, the General Manager of the mining company at Tsumeb. He states that it was known since about 1920, and gives the dimensions as $3 \times 1\frac{1}{2} \times 1\frac{1}{2}$ metres and the estimated weight as 50 tons. Prof. Schneiderhöhn's work in this district during the years 1914–19 is well known, and in collaboration with Mr. Stahl, who worked on the ground during 1922–26, a geological map has been made. But it was not until 1925 that Mr. Stahl saw the meteorite. Incidentally, Prof. Schneiderhöhn gives a graphic description of a brilliant meteor (fireball) which he himself saw at Tsumeb on September 16, 1917; though this, of course, has no connexion with the Hoba meteorite.

At the British Association meeting in South Africa in August 1929, a paper on 'The new Grootfontein meteorite' was read by Prof. W. J. Luyten,[2] Superintendent of the Boyden station at Bloemfontein of the Harvard University Observatory, who visited the meteorite early in 1929. This paper gives a quite inadequate description of the meteorite, and moreover it contains some inaccuracies. The specific gravity is given as 7·96. Since then the meteorite was visited by myself[3] in September 1929, and by Mr. S. G. Gordon[4] of

[1] H. Schneiderhöhn, Das Otavi-Bergland und seine Erzlagerstätten. Zeits. prakt. Geol., 1929, vol. 37, pp. 85–116. Picture of the meteorite on p. 95, and geological sketch-map showing its position on p. 88. [Min. Abstr., vol. 4, p. 261, footnote.] Another photograph of the meteorite, taken by Prof. Schneiderhöhn in 1929, is reproduced in his Mineralische Bodenschätze im südlichen Afrika. Berlin, 1931, p. 18, fig. 15. [Min. Abstr., vol. 4, p. 484.]

[2] W. J. Luyten, The new Grootfontein meteorite. (Title only.) Rep. Brit. Assoc., 1930, vol. 97 (for 1929, South Africa), p. 315.

— The Grootfontein meteorite. South African Journ. Sci., 1929, vol. 26, pp. 19–20. [Min. Abstr., vol. 4, p. 261.] Three of W. J. Luyten's photographs are reproduced in the Scientific American, 1929, vol. 141, pp. 316–317.

[3] L. J. Spencer, Meteoric irons from South-West Africa. Nat. Hist. Mag. (British Museum), 1930, vol. 2, pp. 240–246. [Min. Abstr., vol. 4, p. 422.]

— Min. Mag., 1930, vol. 22, pp. 272–273 (footnote); 1931, vol. 22, p. 493.

[4] S. G. Gordon, The Grootfontein, Southwest Africa, meteoric iron. Proc. Acad. Nat. Sci. Philadelphia, 1931, vol. 83, pp. 251–255, 3 figs. [Min. Abstr.,

Philadelphia in December 1929. A brief mention of it, as one of the 'sights' of the Grootfontein district, has recently been made by Mr. A. W. Clark[1] of the South West Africa Company. Lastly, a brief account of the meteorite has been given by Dr. Paul Range, who visited it in September, 1929, together with a description by Prof. R. Schreiter of the 'iron-shale' surrounding the mass.[2]

FIG. 2. The Hoba meteoric iron, Grootfontein, South-West Africa. Persons, left to right: Prof. L. C. De Villiers (Pretoria), Dr. L. J. Spencer (London), Mr. W. R. Feldtmann (Grootfontein), Mr. E. Schoenfelder (Grootfontein), Mr. von Schmettau (Tsumeb). Photograph by Prof. W. T. Gordon, September, 1929.

The very successful excursion to South-West Africa organized by the International Geological Congress in 1929 ended on September 5 with a visit from Tsumeb to the Abenab vanadium mine and the large meteorite near Grootfontein.[3] Here the party (a small one, as one motor-car broke down on the way, and the majority of the

vol. 5, p. 11.] A picture of the '100-ton iron meteorite' is also reproduced in the 1930 Year Book of the Acad. Nat. Sci. Philadelphia, 1931, p. 50.

[1] A. W. Clark, The ore-deposits of the Otavi Mountains, South-West Africa. Mining Mag. London, 1931, vol. 44, p. 265.

[2] P. Range and R. Schreiter, Der Hoba-Meteorit in Südwestafrika. Centr. Min., Abt. A, 1931, pp. 390–398, 8 figs. [Min. Abstr., vol. 5, p. 11.]

[3] Compt. Rend. Internat. Geol. Congr. XV Sess. South Africa, 1929, Pretoria, 1930, vol. 1, p. 281.

members had elected to visit the game reserve round the Etosha Pan) was conducted by Mr. W. R. Feldtmann, the General Manager of the South West Africa Company. Unfortunately the visit was rather a hurried one and the time was all too short for any detailed study. Nor was it possible to collect any specimens beyond the 'iron-shale' surrounding the mass. The huge block of metal is

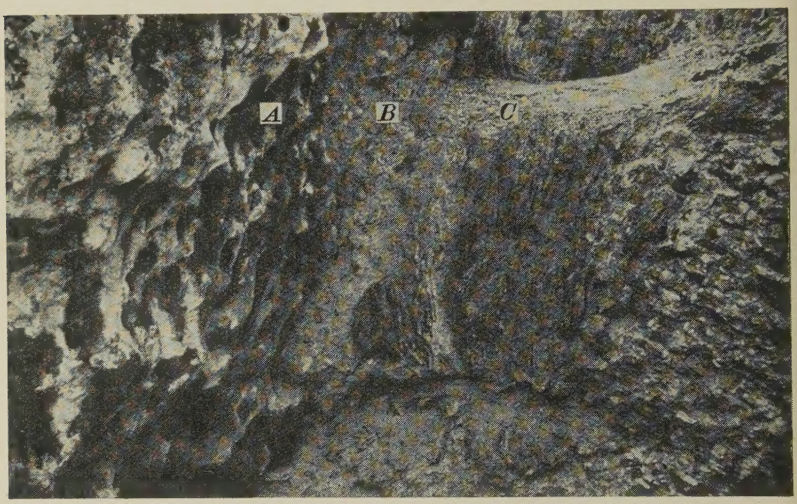


FIG. 3. The Hoba meteoric iron (*A*), Grootfontein, South-West Africa. Side view in the pit, showing the band of 'iron-shale' (*B*) and the surface limestone (*C*). Photograph by Prof. W. T. Gordon, September, 1929.

roughly rectangular in shape with few irregularities and no projecting portions.

When first found only a small portion of the meteorite was showing on the surface. A pit has since been dug partly round the mass; and at one end, where the pit is about six feet in depth, a small portion of the under surface has been exposed. The top surface is approximately flat (fig. 2) and level with the surrounding ground. A dozen people can walk round on the level surface. No attempt has been made to move the mass, and it is not known whether the under surface is flat or not. The mass is embedded in a white, soft and porous, surface limestone (Kalahari Kalk) from which it is separated by a layer one foot in thickness of laminated 'iron-shale' (figs. 3 and 4). This 'iron-shale' is dark-brown to black in colour with a dark-brown streak, and it is magnetic. It consists

largely of limonite with some magnetite and perhaps also trevorite ($NiFe_2O_4$). It shows green nickel stains and is seamed with white calcium carbonate from the surface limestone. The lamination of the shale follows the contour of the meteorite, being vertical at the sides (fig. 3) and horizontal at the base (fig. 4). There is a sharp separation between the shale and the metal, though the metal shows

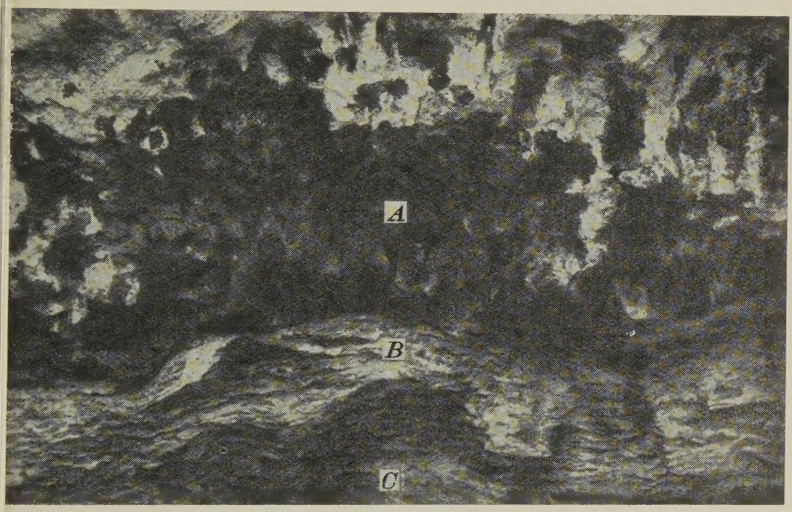


FIG. 4. The Hoba meteoric iron (*A*), Grootfontein, South-West Africa. View of base at bottom of pit, showing the band of 'iron-shale' (*B*) and the surface limestone (*C*). Photograph by Prof. W. T. Gordon, September, 1929.

a little rusting and scaling on the surface. The rock underlying the surface limestone at this spot is granite, close to the junction with the dolomite of the Otavi formation. The ground is level and there is no crater around the meteorite.

The dimensions of the block taken with a steel tape are 295 × 284 cm. (about 10 × 9 feet) on the large flat surface, with a thickness at one end of 122–111 cm. and at the other end of 75–55 cm. With a specific gravity of 7·96 this corresponds to a weight of 60 metric tons[1] for the block. The block shows a complex of broad and shallow concave surfaces. There are no large and prominent pits and no angular corners. It is just a huge block from which it is difficult to detach any portion. I have previously suggested[2] that

[1] Metric ton of 1000 kilograms = 2205 lb. avoirdupois.

[2] L. J. Spencer, Min. Mag., 1930, vol. 22, p. 272.

this characteristic surface of iron meteorites is the result of slow atmospheric weathering, rather than the result of rapid burning during the brief flight through the earth's atmosphere. The foot of 'iron-shale' seen in situ represents the amount of weathering that the mass has undergone since it has lain in the ground. This perhaps indicates the original size of the mass: adding 30 cm. all round, an original weight of 88 tons would be indicated (curiously the same as Mr. Tönnesen's first estimate).

Since my visit, several further visits have been made by Mr. Feldtmann, and he has very kindly supplied me with some further information, including the exact position of the meteorite, as indicated on the sketch-map (fig. 1).[1] With a magnetic compass he found that the mass is magnetized with polarity. The (geographically) north end of the block attracts the south end of the needle and vice versa, and along the side there is a median neutral zone. For the purpose of determining the magnetic axis of the meteorite a six-foot length of drill-steel was magnetized, and Mr. A. W. Clark found that the axis is about 14° east of the earth's present magnetic axis. No doubt the meteorite became magnetized in the earth's field when it fell with a violent concussion; but whether it would be possible to deduce from this figure the date of the fall is very doubtful.

Mr. Feldtmann has also been able to secure a piece of the meteorite, which was generously presented in 1930 to the British Museum by the South West Africa Company. After obtaining official permission from the Administrator of South-West Africa and from the Department of Mines, the piece was sawn off under his personal supervision. This was done by two natives working for two days and with a considerable consumption of hack-saw blades. The specimen (B.M. 1930,976) obtained is a wedge-shaped piece weighing 2489 grams (5½ lb.) with a triangular cut surface measuring 22×9 cm. (about 15 square inches). It shows two earlier cuts that had been made surreptitiously by unauthorized persons, and also the wilful damage done with an oxy-acetylene blowpipe. The meteorite has unfortunately been disfigured all along one top edge by some stupid person with an oxy-acetylene blowpipe. After smoothing and polishing the smallest of the three cut surfaces, and cutting off a piece from the thin end for more convenient microscopical examination, the

[1] Information has also been kindly supplied by Mr. L. G. Ray, the Chief Inspector of Mines for South-West Africa.

specimen now weighs 2444 grams. Mr. Feldtmann also sent 83 grams of the sawdust, which is still available for any further investigation.

The metal is comparatively soft and quite malleable, and is more easily worked than some other meteoric irons. It takes a brilliant steel-grey polish. The larger polished surface (7×6 cm.) shows a few (five) rounded or elongated bronze-coloured areas of troilite, the largest $3 \times \frac{1}{2}$ mm., and the others much smaller. Also numerous minute tin-white specks of schreibersite (or cohenite ?). Both the troilite and the schreibersite (?) are softer than the nickel-iron groundmass, and they are worn down to a lower level. From each speck of schreibersite (?) there is a minute pit with the shape of an acute isosceles triangle, the speck being at the narrow base-line. These pits are parallel over the whole surface and they all point in the same direction. From their sides, first one and then the other, they reflect light simultaneously over the whole surface. This effect was, however, produced only after the surface had been much worn by repeated polishing.

Etching the polished surface with very dilute nitric acid for a few minutes reveals no distinctive structure. Even with longer etching in stronger acid there are no indications of Widmanstätten figures or Neumann lines. The surface is merely dulled. At a certain angle, however, a reflected sheen is shown uniformly over the whole surface, except on a few scattered areas of small size. At another angle the latter show a reflected sheen all together, and the main area is then dull (fig. 5). This effect is mentioned and figured in S. G. Gordon's paper (loc. cit., 1931, p. 253). The main area evidently represents a single crystal individual, and the smaller portions are no doubt in twinned position with respect to the main portion. The boundaries between the two areas are sharply defined, sometimes with straight edges and sometimes dovetailed into each other, suggesting lamellar twinning.

The minute tin-white specks of schreibersite (?) show up more prominently on the etched surface. They are of irregular distribution and have the form of slender needles or curved hairs. In cross-section they show as minute circular areas, scattered singly over the surface or aggregated into small clusters. With rather deeper etching the needles and hairs show a groove along the axis, and the circular areas show a sunken centre.

The larger polished surface on the main specimen is adjacent to

the edge that has been fused with an oxy-acetylene blowpipe. The very thin fused layer was not attacked by the etching reagent, and it forms a narrow (0·1 mm.) bright border on the etched surface. Beyond this, the heating appears to have had no effect on the iron.

A second polished surface (3 × 1 cm., fig. 5), on the small piece cut from the thin end of the specimen and 18 cm. away from the fused

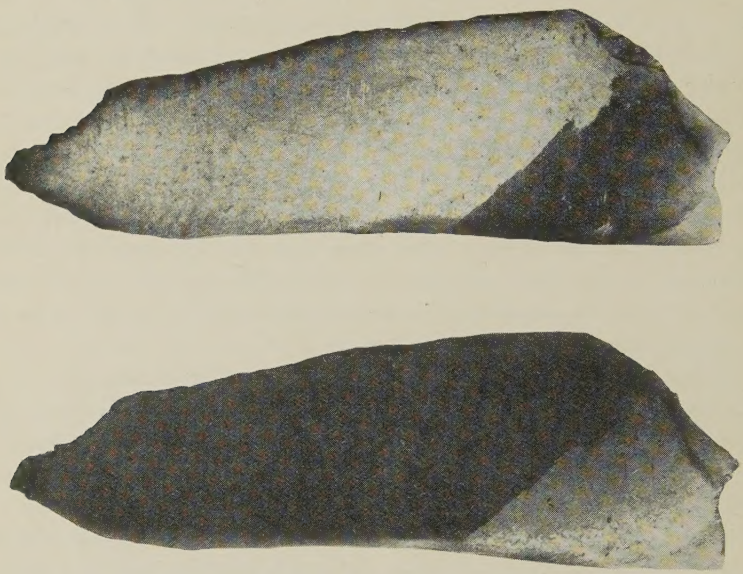


Fig. 5. Photographs taken at different angles of the smaller polished and etched surface (3 × 1 cm.) of the Hoba meteoric iron, showing the oriented sheen. Photographs by H. G. Herring. ×3.

area, has been kindly examined by Dr. J. M. Robertson at the Royal School of Mines, London, with the permission of Prof. Sir Harold Carpenter, F.R.S. The section was repolished and very lightly etched with a 1 % solution of nitric acid in alcohol. His photomicrographs (plate I) taken with an oil-immersion objective show under a magnification of 820 diameters a minute duplex structure somewhat similar to that of plessite. Fig. 7, taken at the junction of the two portions that show oriented sheens at different angles, shows this structure with two directions. Figs. 10 and 11 of one of the schreibersite (?) specks show a border of pale yellow material with a white inner portion. With further etching, as noted above, it seems to be this central portion that is more deeply attacked.

The Hoba meteorite is to be classed as a nickel-rich ataxite.[1] Previously known meteoric irons of this class are tabulated below in the order of their nickel percentages.[2] None of these nickel-irons was observed to fall, and the supposed meteoric origin of the last two with exceptionally high content of nickel has been questioned. In view of its present situation, any origin other than meteoric for the Hoba mass is inconceivable.

Nickel-rich Ataxites.

Name and country.	Date of find.	Ni %.	Fe : Ni.
Babb's Mill, Tennessee (Blake's Iron) ...	1842	11·09	8·0
Illinois Gulch, Montana	1899	12·67	6·9
Deep Springs, North Carolina	1846	13·44	6·4
South Byron, New York	1915	13·47	6·5
Cape of Good Hope, South Africa ...	1793	15·67	5·9
Kokomo, Indiana	1862	15·76	5·3
Iquique, Chile	1871	15·86	5·3
Ternera, Chile	1891	16·22	5·1
Tlacotepec, Mexico	1903	16·23	5·1
Hoba, South-West Africa	1920	16·24	5·1
Linville, North Carolina	1882	16·32	5·1
Smithland, Kentucky	1839	16·42	5·0
Botetourt County, Virginia	1850	17·0	5·0
Shingle Springs, California	1869	17·17	4·8
Babb's Mill, Tennessee (Troost's Iron) ...	1842	17·30	4·7
Weaver, Arizona	1898	17·92	4·5
Klondike, Yukon	1901	18·20	4·4
Morradal, Norway	1892	18·77	4·2
San Cristobal, Chile	1882	25·60	2·9
Lime Creek, Alabama	1834	29·99	2·2
Santa Catharina, Brazil	1875	33·97	1·9
Lafayette, Colorado	1908	59·4	—
Oktibbeha Co., Mississippi	1854	62·01	0·3

Chemical composition.—As with other meteoric irons it would appear that the composition is somewhat variable from place to place, but this may be due to the difficulty in obtaining an average sample and also to inaccuracies of analysis. The earliest analysis

[1] The term ataxite (from *ἀταξία*, disorder) for compact structureless meteoric irons was introduced by A. Brezina in 1896, Die Meteoritensammlung des k. k. naturhist. Hofmuseums, Ann. naturhist. Hofmus. Wien, 1896, vol. 10, p. 295. The same term had been earlier applied by F. Loewinson-Lessing in 1888 (Tschermak's Min. Petr. Mitt., 1888, vol. 9, p. 529) to a brecciated volcanic rock with an irregular arrangement of the fragments.

[2] Compiled from G. T. Prior, Catalogue of Meteorites (British Museum), 1923, and Supplement, 1927; and O. C. Farrington, Analyses of iron meteorites compiled and classified, Field Columbian Museum, Chicago, 1907, publication 120, Geol. Ser., vol. 3, no. 5, pp. 100-105.

made in 1921 in the laboratory of the South West Africa Company at Grootfontein gave Fe 81·29, Ni 17·49 %. Later analyses by Mr. Somerville in the same laboratory gave Fe 81·60, Ni 15·8 %, and Fe 80·47, Ni 17·10 %; and a determination of iron alone Fe 82·8 %. The nickel percentage (17·42) given by W. J. Luyten (1929) is a miscopy of the first Grootfontein analysis. The results of Mr. M. H. Hey's complete analysis made in the Mineral Department of the British Museum are given below (I), together with details of the method employed.

Analyses of the Hoba Meteoric Iron.

	Fe.	Ni.	Co.	Cu.	S.	P.	C.	Total.	Sp. gr.	Fe/Ni.
I.	83·44	16·24	0·76	0·03	trace	trace	0·02	100·49	7·96	5·1
II.	82·40	16·76	0·74	—	0·02	trace	—	99·92	7·971	4·9

I. Analysis by M. H. Hey. Carbon as insoluble residue after distillation of iron in chlorine. Sulphur and phosphorus present, but less than 0·01 %.

II. Analysis by S. G. Gordon, loc. cit., 1931, p. 254.

Through the kindness of Prof. Sir Harold Carpenter a separate carbon determination was made in the Metallurgical Laboratory of the Royal School of Mines, London, on 5 grams of the filings of the Hoba meteorite; this gave C 0·026 %.

Method of Analysis (by M. H. Hey).—A few notes on the method of analysis may not be out of place, as the analysis of meteoric irons presents certain difficulties not sufficiently emphasized by the text-books. The ammonia precipitation invariably carries down some nickel with the iron, and is quite unsatisfactory.[1] The method usually employed is to separate the iron from the nickel and cobalt by the basic acetate precipitation and then precipitate the nickel with dimethylglyoxime and the cobalt with α-nitroso-β-naphthol. This procedure is satisfactory, but tedious; not only must three, or at least two, basic acetate precipitations be made to obtain the iron free from nickel, but it is almost essential to test all the precipitates to make sure the separation has been effective, and this involves bringing the ferric oxide into solution by a pyrosulphate fusion.

The first method tried was to precipitate the nickel first with dimethylglyoxime in ammoniacal tartaric acid solution.[2] This gives a rapid and accurate determination of the nickel, but the subsequent estimation of cobalt and iron is troublesome. Hydrogen sulphide does not precipitate the iron completely unless the excess of dimethylglyoxime is destroyed by evaporation with sulphuric and nitric acids. It was sought to avoid this difficulty by making the determinations of iron, nickel, and cobalt on three separate portions. The iron may be accurately determined by dissolving the filings in dilute sulphuric acid in a current of carbon dioxide; a quantity of pure potassium permanganate rather insufficient to oxidize the whole of the iron is weighed out, dissolved and added, and the

[1] Cf. G. T. Prior, Min. Mag., 1914, vol. 17, p. 132.

[2] Method of O. Brunck, Zeits. angew. Chem., 1907, vol. 21, p. 1849; 1914, vol. 27, p. 317.

titration completed with standard permanganate solution. We have thus reliable methods for the iron and nickel, but a rapid and reliable method for the cobalt could not be found. The old cobaltinitrite method was found to give too low results (0·11 and 0·13 % Co in the Mbosi and Hoba meteorites, subsequently found to contain 0·62 and 0·76 % respectively). It is, however, useful to supplement an analysis by the method outlined below, or by the basic acetate method, with a determination of either the iron or the nickel by the above methods. Such a check is particularly useful when the basic acetate method is used, avoiding the necessity of a pyrosulphate fusion to test the purity of the iron precipitate, and was used by Dr. Prior (loc. cit.).

While these first attempts to find a satisfactory substitute for the basic acetate precipitation failed, it was found possible to base a rapid and reliable method on the process of F. A. Gooch[1] for the separation of iron from the complex alumina precipitate of rock analysis (consisting of ferric oxide, alumina, titania, zirconia, rare-earths, phosphoric acid, &c.). Gooch obtained an accurate separation by heating the oxides in a current of hydrogen chloride containing some chlorine at 200 to 300° C., pure ferric chloride subliming while the other oxides remained behind unchanged.

Now neither nickel, copper, nor cobalt chloride is volatile at 300° C.[2] If, therefore, we heat the filings to 200 to 300° C. in a current of chlorine gas, the iron should sublime as ferric chloride, while cobalt, copper, and nickel chlorides remain behind in the boat. This proves to be the case. Using ½ to 1 gram of coarse filings,[3] and heating in a current of chlorine, first for an hour at 200° to 250° C., then for three hours at 250° to 300° C. there remains in the boat a chamois-yellow powder of $NiCl_2$, while a fine black sublimate of $FeCl_3$ forms where the tube leaves the oven.[4] A couple of trap flasks, one empty, and one filled with water, trap any ferric chloride carried forward by the stream of gas, and also collect the phosphorus and sulphur. The chlorine is best generated from manganese dioxide, salt, and strong sulphuric acid; it then needs no further drying, while its hydrogen chloride content does no harm.

The distillation completed, the residue of nickel and cobalt chlorides in the boat is dissolved in water and a little acid. It will usually be found that some of the coarser filings have become coated with nickel chloride and are not completely attacked; they dissolve in the acid. The solution is filtered through a tared Gooch crucible, and any small residue of carbon, &c., weighed.[5] In the

[1] F. A. Gooch, Methods in chemical analysis, New York, 1912, p. 504. F. A. Gooch and F. S. Havens, Amer. Journ. Sci., 1899, ser. 4, vol. 7, p. 370. W. F. Hillebrand, Bull. U.S. Geol. Surv., 1919, no. 700, p. 133.

[2] Cobalt chloride is stated to be volatile in a current of chlorine (Roscoe and Schorlemmer, Treatise on chemistry, 4th edition, London, 1907, vol. 2, p. 1255). No temperature is given, but presumably it must have been at least 400° C. I have failed to find any volatilization at 300° C. in special experiments with pure $CoCl_2$.

[3] The amount used should be regulated to the class of meteorite. With nickel-rich ataxites and finest octahedrites ½ gram will suffice, while for coarsest octahedrites, hexahedrites, and nickel-poor ataxites, 1 gram will be necessary.

[4] The boat should be placed about 10–12 cm. from the point where the tube leaves the oven. The tube around the boat and for at least 5 cm. beyond it should be quite free from sublimate when the reaction is complete.

[5] Sublimation of the iron in a current of chlorine is sometimes used in iron

filtrate a small amount of iron is usually present, from the unattacked metal above mentioned; it is precipitated with ammonia, dissolved and reprecipitated, and the precipitate reserved to add to the main iron precipitate. Being only one or two per cent. of the total, this small iron precipitate does not carry down any weighable amount of nickel with it.

In the filtrate from the small iron precipitate, nickel is precipitated with dimethylglyoxime. The filtrate from the nickel dimethylglyoxime is acidified and cobalt precipitated with α-nitroso-β-naphthol. Finally, a small amount of cadmium chloride (0·02–0·05 gram) is added to the filtrate from the cobalt, and hydrogen sulphide passed in. The cadmium sulphide serves as a 'collector', making it possible to filter off the minute precipitate of copper sulphide; after solution in dilute nitric acid, the copper is determined colorimetrically with ammonia, the solution being evaporated if necessary to a small bulk.

The ferric chloride sublimate in the tube is dissolved and washed out into the second trap flask, into which the first (empty) one is also washed out. The solution is made up to a suitable volume in a measuring flask, well mixed, and half taken for the determination of iron; as no other metal is present, a single ammonia precipitation and quite a short washing suffices.[1] In the other half of the solution, sulphur, now present as sulphuric acid, is determined as barium sulphate, while phosphorus is precipitated and weighed as ammonium phosphomolybdate.

The method outlined above has particular advantages where the amount of material available is small, for it is possible, by taking advantage of the colorimetric methods for copper, cobalt, and phosphorus, to determine these constituents, as well as the iron and nickel, on a single portion of as little as 0·2–0·3 gram with reasonable accuracy. The one disadvantage of the method, the need for setting up a chlorine generator, tube-oven, and absorption flasks, is small, and would be negligible in a series of analyses.

In order to test this method, a trial analysis was made of the Mbosi meteorite, which had already been analysed by Mr. F. Oates (Min. Mag., 1931, vol. 22, p. 490); the results obtained (loc. cit., p. 492) were in excellent agreement with those of Mr. Oates.

The Hoba meteorite was analysed by the above method, using 0·5017 gram of filings, with the results given on p. 12. A separate determination of iron by the semi-volumetric method above described gave 83·70 %; a determination of nickel by the dimethylglyoxime method gave 16·35 %; and one of iron and cobalt together after destruction of the organic matter in the filtrates from the nickel gave 84·13 %.

The specific gravity determined by hydrostatic weighing on a piece of 26 grams gave the value 7·96. A determination made on the

and steel analysis (see, e.g., A. A. Blair, Chemical analysis of iron, 6th edition, Philadelphia, 1906, p. 73), but a dull red-heat appears always to be employed.

[1] If only $\frac{1}{2}$ gram of filings were taken and the amount of sulphur is likely to be small, the whole solution may be used for the sulphur determination, and then halved for the iron and phosphorus determinations. In this case the ferric hydroxide should be dissolved and reprecipitated.

filings by the pyknometer method in carbon tetrachloride gave 7·87.

The magnetic 'iron-shale' surrounding the mass of iron has also been analysed with the following results:

		I.	Mol. ratios.		II.	Mol. ratios.	
Fe_2O_3	...	58·14	0·3641		65·48	0·4101	
FeO	...	13·25	0·1844	} 0·4056	5·60	0·0779	} 0·2047
NiO	...	16·13	0·2160		8·88	0·1189	
CoO	...	0·39	0·0052		0·59	0·0079	
CaO	...	nil	—		—	—	
H_2O	...	11·83	0·6566		8·47	0·4701	
Total	...	99·74			89·02		
Sp. gr.	...	—			4·021		

I. Analysis of 'iron-shale' by M. H. Hey.
II. Partial analysis by S. G. Gordon (loc. cit., 1931, p. 254).

Mr. Hey reports that during solution of the material in acid there was a slight effervescence, which may be due to the presence of metallic iron, or perhaps of iron or nickel carbonate. The excess of monoxides over Fe_2O_3 shown in his analysis suggests metallic iron, but there would be no surplus of Fe_2O_3 for combination with the water. The material is clearly a mixture. Calculating all the nickel (and cobalt) as $NiO.Fe_2O_3$, Mr. Hey's analysis would correspond with 51·84 % and Mr. Gordon's with 22·72 % of trevorite;[1] but in neither case are the results consistent with a mixture of limonite, haematite, magnetite, and trevorite.[2]

In the 'iron-shale' which I was able to supply to Prof. V. M. Goldschmidt,[3] he found germanium to the extent of 0·01–0·1 %.

The Largest Meteorites.—Like fish stories, those about big meteorites are also apt to dwindle somewhat when examined critically. The recorded weights of most large meteoric irons are merely estimates, and, owing to the irregular shape of the masses, these estimates have varied between wide limits. Further, it is usually not stated whether the 'tons' are the metric ton (2205 lb.), the English long ton (2240 lb.), or the American short ton (2000 lb.); but the error

[1] Trevorite of A. F. Crosse (1921) was shown by T. L. Walker (1923) to be a distinct mineral $NiFe_2O_4$ of the spinel group. [Min. Abstr., vol. 2, p. 249.]

[2] See E. V. Shannon, The oxidation of meteoric irons. . . . Proc. U.S. Nat. Mus., 1927, vol. 72, art. 21. [Min. Abstr., vol. 3, p. 534.]

[3] V. M. Goldschmidt, Die Naturwissenschaften, 1930, vol. 18, p. 1007; Verhandl. Gesell. Deutsch. Naturfor. Ärzte, 1931, vol. 91 (for 1930, Königsberg i. Pr.), p. 1007. [Min. Abstr., vol. 5, p. 7.]

here is inappreciable in comparison with that of the estimate of the weight.

The largest single block preserved in any museum is the fine mass of 'Ahnighito', or 'The Tent', in the American Museum of Natural History in New York City. This was transported in 1897 from Cape York, north Greenland, by Admiral R. E. Peary,[1] who himself estimated the weight at 90 to 100 tons. It is now put at '36½ tons'.[2] Although not stated, this weight would appear to be in short tons, for O. C. Farrington[3] gives the equivalent as 33,113 kilograms; that is, rather over 33 metric tons, or 32½ English (long) tons. Two other masses of the Cape York meteoric iron transported by Peary to the American Museum of Natural History are 'The Woman' of about 3000 lb., and 'The Dog' of about 1100 lb. More recently, in 1925, another mass, the 'Savik', has been transported from Cape York to Copenhagen; and in this case the weight was determined by actual weighing to be 3401·7 kg. (= 3·4 metric tons).[4]

Another large mass, also in the American Museum of Natural History, of which the weight has been actually determined, is that of Willamette, Oregon. This was weighed on the railway scales at Portland, Oregon, giving 31,107 lb. This weight is usually stated as 15·6 or 15½ tons (i.e. short tons); it is equivalent to 14·2 metric tons, or 13·9 long tons.

An enormous mass of meteoric iron, said to measure about 100 metres in length and about 40 metres in height, has been stated to have been found in 1921, together with other smaller masses, about 45 km. SW. of Chinguetti in the Adrar desert, Mauretania, French West Africa. It is compared with an overhanging cliff partly buried in a sand dune. A piece weighing 4½ kg. was described by Prof. A. Lacroix[5] in 1924, but there has been no further mention or confirmation of the larger mass. It sounds rather like a traveller's story, or perhaps metres may be a miscopy for centimetres.

[1] R. E. Peary, Northward over the 'Great Ice' . . . and an account of the discovery and bringing home of the 'Saviksue' or great Cape-York meteorites. London, 1898, vol. 2.

[2] E. O. Hovey, Amer. Mus. Nat. Hist. New York, Guide Leaflet, 1907, no. 26, p. 23; F. A. Lucas, ibid., 1926, no. 64, p. 14. [Min. Abstr., vol. 3, p. 395.]

[3] O. C. Farrington, Meteorites. Chicago, 1915. In a chapter (pp. 54–59) on the size of meteorites, where the 'ton' unit has not in all cases the same value.

[4] O. B. Bøggild, Meddel. om Grønland, 1927, vol. 74, p. 15. [Min. Abstr., vol. 3, p. 535.]

[5] A. Lacroix, Compt. Rend. Acad. Sci. Paris, 1924, vol. 179, p. 309. [Min. Abstr., vol. 3, p. 393.]

Some other large meteoric masses have been inferred, but never actually found. The 'Meteor Crater' near Cañon Diablo in Arizona, with a diameter of 4000 feet and a depth of 570 feet was probably formed by the impact of a gigantic meteorite.[1] Many masses of iron with a total weight of over six metric tons, the largest piece 460 kg., have been found around the crater, but borings within the crater have not revealed any larger mass. The Siberian meteor of June 30, 1908, was supposed to have fallen as a meteorite and variously estimated to weigh from 130 to half a million tons, but nothing has ever been found.[2]

The following list of the largest known and authenticated masses of meteoric iron is a revision of that given by Prof. O. C. Farrington in his book 'Meteorites' (1915, p. 58).

The Largest Meteorites.

Name and country.	Date of find.	Metric tons.	Present location.
Hoba, South-West Africa	1920	60	In situ
Cape York, Greenland ('Ahnighito') ...	1895	33·1	New York City
Bacubirito, Mexico	1863	24½	In situ
Willamette, Oregon	1902	14·2	New York City
Chupaderos, Mexico (I)	1852	14·1	Mexico City
Mbosi, Tanganyika Territory	1930	12	In situ
Morito (=San Gregorio), Mexico	1600	10·1	Mexico City
Chupaderos, Mexico (II)	1852	6·77	Mexico City
Bendegó, Brazil	1784	5·36	Rio de Janeiro
Cranbourne, Victoria	1854	3·50	British Museum
Cape York, Greenland ('Savik')	1913	3·40	Copenhagen

The above are all irons. The largest single meteoric stone is one of 338 kg. (745 lb.), which fell quite recently, on February 17, 1930, at Paragould, Arkansas.[3] The next largest stone is that which fell on June 9, 1866, at Knyahinya, Czechoslovakia, and weighs 293 kg.; this is in the Natural History Museum at Wien. Other large stones, Long Island, Kansas (564 kg.), and Bjurböle, Finland (330 kg.), were broken into fragments by their fall, either in the atmosphere or when striking the ground. The largest single stone in the British Museum

[1] Min. Abstr., vol. 4, pp. 427–428; vol. 5, p. 16.

[2] Min. Abstr., vol. 2, p. 357; vol. 3, pp. 92, 256; vol. 4, pp. 261, 428; vol. 5, p. 17.

[3] Annual Report Field Museum of Natural History, Chicago, for 1930, 1931, vol. 8, p. 374, and plate 29. The weight of this stone has also been given as 820 lb. Apparently 745 lb. is the weight of the portion now in the Chicago Museum. [Min. Abstr., vol. 5, p. 12.]

collection is that of Parnallee, India, which fell on February 28, 1857, and weighs 60·55 kg. (133½ lb.).

Explanation of Plate I.

Photomicrographs of the polished and etched section (fig. 5 in text) of the Hoba meteoric iron, Grootfontein, South-West Africa.

(Photomicrographs by Dr. J. M. Robertson.)

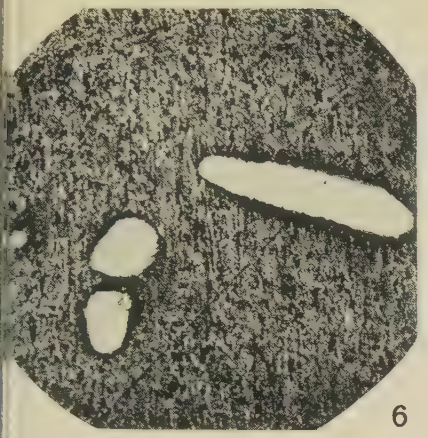
Fig. 6. Minute plessite-like structure with blebs of schreibersite (?). ×100.

Fig. 7. Two areas of plessite-like structure with different orientations. ×100.

Figs. 8 and 9. Plessite-like structure. ×820.

Fig. 10. Schreibersite (?) in groundmass of plessite. ×820.

Fig. 11. Schreibersite (?) area. The bordering portions outside the dark lines are pale yellow and the inner portions are white. ×820.



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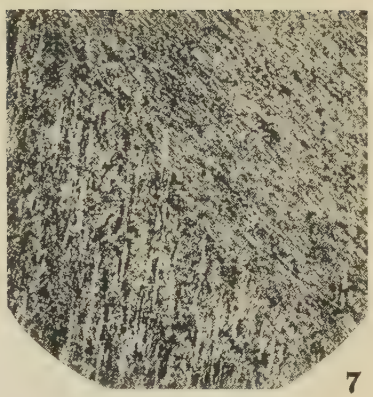

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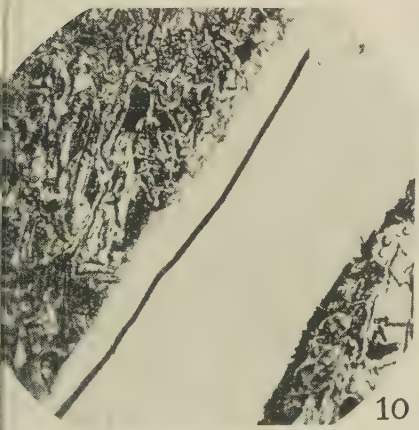

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11

L. J. Spencer: The Hoba Meteoric Iron.

The meteorite craters at Henbury, Central Australia.[1]

(With Plates II and III.)

By Arthur Richard Alderman, M.Sc., F.G.S.
Lecturer in Geology and Mineralogy, University of Adelaide.

[Communicated and read by Dr. L. J. Spencer, F.R.S., November 3, 1931.]

IN the early part of 1931 public interest in South Australia was stimulated by the fall of the Karoonda meteorite[2] on November 25, 1930, and its subsequent discovery by an Adelaide University party led by Prof. Kerr Grant. In consequence of this Prof. Grant was informed separately by Mr. B. Bowman of Tempe Downs and Mr. J. M. Mitchell of Oodnadatta that fragments of meteoric iron were to be found surrounding several crater-like depressions near Henbury Cattle Station in Central Australia. The number of craters was variously described as three and five.

Prof. Kerr Grant placed this information before the authorities of the South Australian Museum, and Prof. Sir Douglas Mawson, the Honorary Mineralogist to that institution, immediately suggested that the Museum should investigate the reports. The author consequently was commissioned by the Museum authorities to make a preliminary survey of the area. In this he was fortunate to be assisted by Mr. F. L. Winzor of the Chemistry Department, University of Adelaide.

Locality.

Henbury is situated on the dry water-course of the Finke River about 120 miles, by motor, from Rumbalara Railway Station. This distance is shortened by about ten miles if the journey is made by camel, the usual means of transport of the country. The meteorite locality (fig. 1) is situated seven miles WSW. of Henbury and adjacent to a strong ridge which runs in an E.-W. direction and which forms an outlying spur of Bacons Range. The locality is known

[1] Published by permission of the Board of Governors of the South Australian Museum.

[2] K. Grant and G. F. Dodwell, Nature, London, 1931, vol. 127, pp. 402, 631. [Min. Abstr., vol. 5, p. 15.]

locally as the 'Double Punchbowl', due apparently to the two largest craters being in close proximity.

Geologically, the Henbury area consists of Ordovician sediments, mostly sandstones and quartzites, which are known as the Larapin-

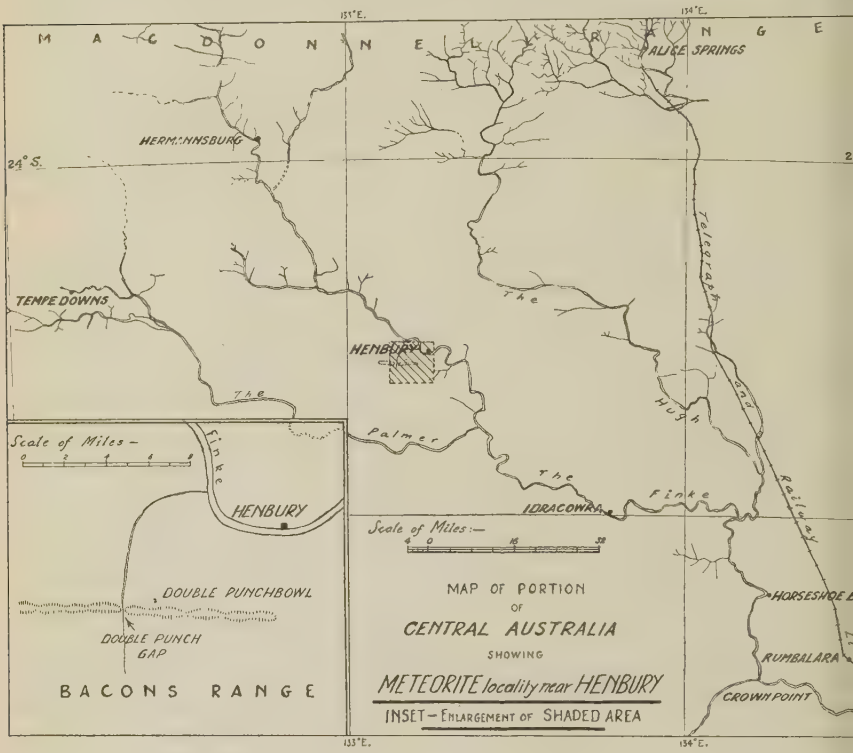

FIG. 1. Sketch-map of the locality.

tine Series, the nomenclature being derived from the aboriginal name for the adjacent Finke River. Characteristic Ordovician fossils are found in these beds at Tempe Downs, some sixty miles distant. At Henbury wide alluvial plains are interrupted by ridges and hills which generally consist of the more resistant quartzites.

The Craters.

The view of the craters from the plain is decidedly unimpressive (Plate II, fig. 4), so much so that they could very easily escape the notice of an observer who did not approach quite close to them.

The only indication of anything unusual is the presence in one of them of green trees, the tops of which are prominent in a region where, owing to the aridity, green vegetation is extraordinarily scarce.

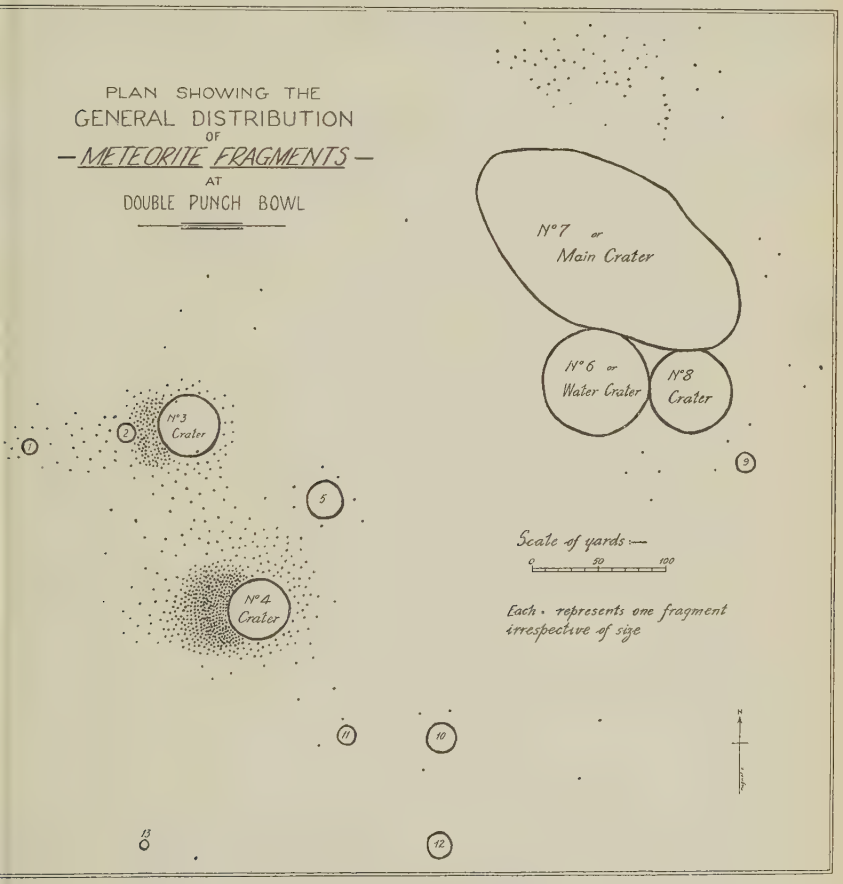

Fig. 2. Plan showing the general distribution of the craters and of the meteorite fragments around them.

The number and size of the craters were found to be much greater than was anticipated. Within an area of half-a-mile square at least twelve probable craters were located (fig. 2), varying in size from the smallest with a diameter of about 10 yards up to the largest of which the longest diameter is about 220 yards from rim to rim.

The author believes that a more detailed survey over a wider area will probably lead to other craters being located.

There is one extremely useful point which greatly aids in the locating of the smaller craters, and also in their identification in cases when the crater walls have been removed by erosion. That is the presence of mulga trees. Mulgas are, in this area, practically confined to the water-courses, which, although generally dry, occasionally flow after rain. The craters, however, almost invariably contain a clump of mulgas. This is due to the concentration in the centre of the crater of any rain-water falling within the crater walls. The inward wash of rain has naturally filled up a great deal of the central depression and the finer sediment has formed a highly impervious surface after the nature of a 'clay-pan'. Water is thus preserved in the crater for a much longer period than outside the walls.

The greatest interest was attached to the two largest craters, which may be called the Main Crater and the Water Crater (nos. 7 and 6). Viewed from the outside, a very gentle slope rises up to the brim and in appearance entirely resembles one of the low elevations which foot the adjacent quartzite ridges. However, as soon as the rim of the Main Crater is reached the effect is startling. A huge depression is seen, 50–60 feet deep and of oval shape, being about 220 yards in its longest axis and 120 in its shortest. Mulga trees and grasses cover the floor, which consists of cracked mud-cakes resembling the floor of a 'clay-pan', and which apparently retains water for some time after rain (Plate II, fig. 5). The crater walls are generally steep near the summit (Plate III, fig. 6), but at lower levels slopes of talus reach more gently in towards the centre of the depression. The height of the walls from floor to rim is on the average from 40–50 feet, but it is evident that they have formerly been considerably higher than they are at present. The walls themselves consist for the most part of shattered and crushed fragments of sandstone and slaty rock varying in size from the finest powder up to large blocks several cubic feet in volume. In one or two places slaty rock, very much shattered, has the same dip as the country-rock and seems to be in situ in the walls. This point is of interest and will be mentioned later.

Adjacent to the Main Crater and lying to the south of it are two other craters, the larger of which may be called the Water Crater. A water-course having broken through the walls, an inflow of water

evidently results after rain. This water is apparently preserved for some weeks after the rain has fallen. This has led to the greater development of vegetation, and both mulgas and acacias have grown in this crater to a size unusual in the area. One or two trees (apparently *Acacia salicina*) have a height of about 45 feet, the diameter of the trunk being up to 21 inches. In shape the Water Crater is roughly circular with a general diameter of about 80 yards. The walls vary in height from 12 25 feet, reaching the maximum at that point where they divide the Main Crater from the Water Crater. The general description of the walls of the Main Crater may be applied to the walls of this and all the other craters.

A summarized description of the craters follows (fig. 2):

No. 1. Somewhat indefinite owing to the complete removal by erosion of the crater walls. An isolated circle of mulgas with a 'clay-pan' floor, together with the presence of meteoric iron fragments surrounding it, leaves little doubt in the author's mind that this is a former crater. Probably originally circular, with a diameter of possibly 25 yards.

No. 2. Similar to no. 1, but somewhat larger. Circular, with diameter of possibly 30 yards.

No. 3. A very well-defined crater, circular with a diameter of about 45 yards. General height of walls 10–18 feet. About 160 iron fragments, many being very small, were found surrounding this crater, and of this number about four-fifths were lying to the west. A large jagged piece, weighing 13 lb., was found within the crater walls. Another large mass was found in a position where a water-course had at one point broken through and washed away the crater wall.

No. 4. Very similar to no. 3. Circular, diameter about 45 yards, general height of walls 10–20 feet. In the immediate neighbourhood of no. 4 about 500 fragments of various sizes were found. Of these nearly 400 were on the west side of the crater. As noted below, about 100 of these were lying within an area of 6 by 6 feet.

No. 5. Circular, diameter 25 yards, low walls. Boring in the 'clay-pan' floor showed a depth of 8 feet of fine soil before coarse rock fragments prevented further sinking.

No. 6. The Water Crater. Roughly circular, with diameter of 80 yards. Height of walls 12–25 feet, the highest part being that which divides this crater from the Main Crater. A water-course has broken through the wall on the south side, water being preserved in the pan for some time after rain. This crater contains mulga and acacia trees, the latter reaching a height of 45 feet.

No. 7. The Main Crater (Plate II, fig. 5; Plate III, fig. 6). Oval in shape, with its principal axes 220 and 120 yards from rim to rim, and 170 and 70 yards across the floor. The peculiarity of shape is possibly due to two large masses landing simultaneously and in close proximity. Height of walls averages 40 50 feet. Fragments of iron mostly on north side.

No. 8. Well-defined, circular, diameter 55–60 yards. Height of walls varies from 3–15 feet, being greatest where no. 8 is divided from the adjacent Main and Water Craters.

No. 9. Ill-defined and doubtful; the topography, however, suggests a small crater.

No. 10. Like nos. 11, 12, and 13 is situated on a low sandstone ridge to the south of the main craters and to the north of the prominent ridge of siliceous breccia previously mentioned as a spur of Bacons Range. No. 10 is circular, with a diameter of about 20 yards; low walls. It is about SSW. of the main group of craters.

No. 11. On ridge, circular; diameter about 15 yards.

No. 12. On ridge. A very well-defined circular crater sunk into side of ridge, the walls reaching 12 or more feet on the highest side; diameter 20 yards. (Plate III, fig. 7.)

No. 13. Rather indefinite, but there can be very little doubt that this is a crater; diameter about 10 yards.

Meteorite Fragments.

A great number of metallic meteorite fragments are scattered over a wide area (fig. 2). Those collected are of all shapes and vary in weight from a fraction of an ounce up to $52\frac{1}{2}$ pounds. The shape of many of them suggests that they were fragments torn or scaled off a large mass, whereas others seem to have fallen as complete units. This, together with the fact that a number of craters were located, suggests the extreme probability that many of the fragments were torn off large masses immediately before or during impact with the earth and that others fell at the same time but separately. It was, of course, owing to the impact of the largest members of this meteoric shower that the craters were formed.

It was extremely noticeable during the collection of material that in many instances a number would be found within an area of perhaps a square foot or so, the surrounding area being practically devoid of fragments. In an area of 6 by 6 feet near crater no. 4 over a hundred fragments were collected.

These facts are suggestive of the breaking up of large masses. The greatest number of fragments were found surrounding craters nos. 3 and 4 and generally to the west of them. Many of the larger pieces were found at some distance, perhaps 100–200 yards from the craters, whereas the small fragments were mostly close to the crater's edge. Very few were found within the walls of any of the craters. Around the group of large craters (nos. 6, 7, and 8) fragments were notably scarce, except on the northern side. This, however, is easy to understand. Immediately after the fall of the meteoric material the crater walls must have been very considerably higher than they are now and fragments of meteorite may have

covered the existing land surface. Erosion has, however, since removed material from the walls and it has washed downwards, both inwards into the craters and outwards on to the plain. The material so removed has covered up most of the meteoric fragments except in such places where a slight alteration of the drainage has again uncovered them. It was noticeable that most of the fragments found near the main craters were in shallow water-courses.

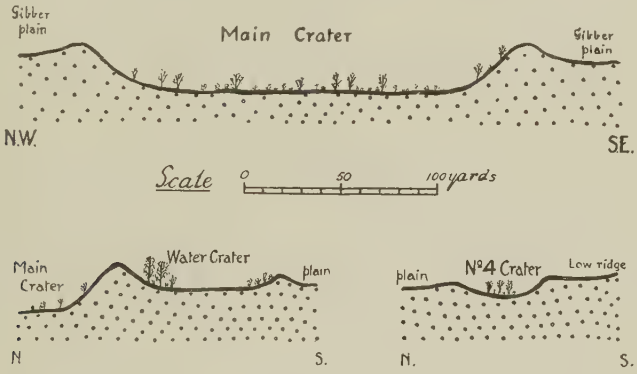

FIG. 3. Sections through the craters.

Absence of Positive Evidence of Iron Masses in the Craters.

None of the craters showed any evidence, at the surface, of containing a large mass of meteoric iron. Further, the presence of fragments of iron within the crater walls was rare. This, of course, was to be expected. Certain simple observations were made, therefore, in an attempt to locate masses of meteoric iron in the craters. A light hand-boring tool was used in one of the smaller craters.

Crater no. 5 was considered to be the most suitable for this purpose. A hole to the depth of 8 feet was sunk through fine loamy soil. At this depth rock fragments, apparently washed inwards from the walls, prevented further sinking. This showed that the small crater no. 5 had originally been at least 8 feet deeper than it now is. If any meteoric mass has penetrated to a depth of more than 8 feet below the present floor of a small crater like no. 5, the depth to which such a mass has penetrated below the larger craters must be very considerable.

An experiment was also made to see if a compass-needle showed any deviation on approaching and passing the Main Crater. Traverses

were made with this end in view, but the prismatic compass used gave results which could not be considered beyond the limits of experimental error.

Although these observations gave results which can only be considered as negative, the author believes that further work along these lines should be proceeded with as soon as possible. In such a case as this the use of geophysical methods seems to be ideally suited. If, as at the great Meteor Crater at Cañon Diablo in Arizona, magnetic methods prove to be somewhat unsatisfactory, it is highly probable that good results would be obtained by the use of gravimetric, seismic, or electrical methods.

Effects of Impact.

The excavating effect of the fall of a large meteoric mass is of course self-evident, and the intense shattering and crushing of the surrounding country-rock are only to be expected. The walls in all cases consist of unconsolidated fragmentary rock-material varying in size from the finest powder up to large masses several cubic feet in volume. The effects of shearing stresses are also to be noted in many specimens.

Besides the formation of the twelve or more craters mentioned, the impact of the meteoric bodies with the earth has left traces of other effects which are extremely interesting. One of these phenomena is shown particularly well by crater no. 3. Radiating outwards into the plain from the crater walls can be seen five or six low ridges of sandstone. These suggest ' dikes ' of a hard rock which has resisted erosion more successfully than the surrounding country-rock. They consist, however, of sandstone which is apparently identical with that to be found anywhere in the neighbourhood. The ' ridges ' are only a few inches higher than the surrounding surface of the plain, but consisting as they do of small blocks of sandstone of which the surface is blackened due to weathering, they are easily distinguished from the prevailing reddish colour of the surrounding gibbers.[1] These ' dikes ' radiating outwards from the crater immediately reminded the author of the ' percussion figures ' obtainable in mica under suitable conditions. Although traces of similar ridges were found around some of the other craters, particularly no. 4, none were as well defined as those described around no. 3. The

[1] Gibber, aboriginal Australian for a large stone or boulder.

length of these ridges varied considerably, but one could perhaps mention 30 yards as an average distance from the crater rim that a 'dike' could still be traced on the plain.[1]

Another point of extreme interest was the discovery on the plain to the north of the Main Crater of black glassy material greatly resembling the glass of fulgurites. This is seen in some specimens to be vesicular, in others to be cementing rock fragments. There is little doubt that this has been formed by the fusing of the country-rock by the enormous heat of impact of the meteorite. It is a point of interest that glassy siliceous matter apparently of similar origin has been found at the great meteorite crater at Cañon Diablo in Arizona.

Direction of Fall.

Until the position of any iron masses buried in the craters has been located, the direction of fall of the meteoritic bodies must be more or less a matter of conjecture. There is, however, one point which may give some indication of the direction in which the bodies were travelling. Notes were made as to the general position of all meteoritic specimens collected. From this it was seen that the material was generally concentrated on the western side of the craters (fig. 2). This was particularly noticeable in the case of craters nos. 3 and 4. Around these craters there seemed to be no indication that such factors as prevailing winds or surface drainage had favoured the uncovering of meteoritic material on one side more than the others.

This fact is subject to two interpretations depending on whether the majority of the fragments were formed by the impact having a shattering effect on the larger masses, or whether the fragments had existed separately for some time before landing. If the former supposition is correct, one would expect that the fragments had been deposited or 'splashed' on the farther side of the crater. That is, the meteoritic bodies possessed an east to west movement. If the latter is the correct supposition, one would expect that the smaller bodies, not possessing the momentum of the larger, would be impeded to a greater extent by air-resistance, and would thus fall short of the larger masses. This would then suggest a movement from west to east.

[1] Some of the craters of the moon (e.g. Copernicus) show somewhat similar radiating ridges. This may perhaps lend some support to the theory that the lunar craters are of meteoric origin.

It is, of course, difficult to realize how a huge mass of iron would behave under the conditions which must have prevailed when the meteorite landed, but one would expect that the impact would cause the bodies to be at least partly shattered. This idea is supported by the shape of many of the fragments. The absence of the minute 'pitting' over the whole or part of the surface of a great number of the fragments also suggests that the period of their separate existence must have been a very short one.

Age of the Fall.

Judged from human standards, the age of the fall must be considerable. There are many indications that it is by no means recent, but one cannot as yet make any positive determination of its age. Summarized, these indications are :

(1) The complete oxidation and disintegration of certain of the iron fragments. These and other geological processes proceed with extreme slowness in a climate of such aridity. The average annual rainfall for the locality is probably about six inches. Some fragments were found which consisted entirely of scaly ferric oxide.

(2) The presence of fully grown mulga and *Acacia salicina* trees would put a certain minimum on its age. The author believes, however, that generations of trees have lived and died in the craters since the meteoric fall. The trunks of many dead mulgas are to be seen everywhere, some apparently of great age. The mulga is a notably slow-growing tree.

(3) Inquiries from aborigines of the district gave negative results. None of them had any ideas as to the origin of the craters. If the fall had taken place since the human occupation of the area one would have expected accounts of such a notable happening to be handed down from generation to generation, and that also the locality would be regarded with superstitious awe. The aborigines, however, showed no interest in the craters.

(4) In the walls of the main crater some shattered slaty rock has the same dip as that of the surrounding country-rock and may possibly be in situ. This is several feet higher than the general level of the plain, and may indicate that the level of the plain has been reduced by several feet since the formation of the crater, which in such a climate would require a very long period of time. The rock in situ in the crater walls would have been protected from

erosion by the superincumbent layer of fragmentary material which formed the upper part of the previously higher walls. The occurrence of such rock in the walls is, however, perhaps accidental, i.e. it may have been thrown up by the impact and is not in situ at all.

It will be seen that the age indications are very vague indeed. The author is, however, of the opinion that the fall took place a very long time ago and that the age of the craters must be reckoned in terms of thousands of years.

Conclusion.

This description would not be complete without some reference to the meteorite craters at Cañon Diablo (or Coon Butte) in Arizona, and near the Tunguska River in Siberia. The Cañon Diablo crater is, of course, much larger than the largest at Henbury, being some three-quarters of a mile in diameter and with a depth of 570 feet from floor to rim. There are, however, many points of similarity between the two occurrences. Dr. Merrill's general description [1] of the nature of the Cañon Diablo crater could easily be applied to the larger ones at Henbury with but few modifications. Other notable points of similarity are the nature and occurrence of the iron fragments and the presence of fused country-rock. Dissimilarities which may be particularly noted are the large number of craters in Central Australia compared with the single large one in Arizona; also the oval shape of the main crater at Henbury.

Fewer details are available concerning the craters in Siberia. Apparently the largest crater is 150 feet in diameter and about 12 feet deep, and it is interesting to note that digging in one of these craters to a depth of 30 feet failed to reveal any meteoric material. The largest of the Siberian craters is thus much smaller than the main crater at Henbury, so that it is possible that meteoric material at Henbury may be buried to a very considerable depth. A bore sunk in the Cañon Diablo crater reached a hard mass at about 1376 feet. It is, however, still uncertain that this is the main bulk of the meteorite.

Bearing these facts in mind the author would suggest that further work at Henbury should obviously be along the following lines:—

(1) That a wider survey of the area be made. Owing to difficulties of transport and lack of the necessary time, only a comparatively small area was examined.

[1] G. P. Merrill, Smithsonian Miscell. Collections, 1908, vol. 50 (Quarterly Issue, vol. 4), p. 461.

The author believes that a wider survey may lead to the discovery of more craters, some of which may be of considerable importance.

(2) That use be made of geophysical methods in an attempt to locate the position of masses of meteoric iron in any of the craters. The locality, the type of country-rock, and the nature of the material to be located, seem most ideally suited to the use of such methods.

(3) That if the position of a mass of iron be located by geophysical means boring operations could then be proceeded with advantageously. Boring or drilling would certainly be of great value in prospecting the main craters. In some of the smaller ones it is possible that the meteoric material might be revealed by actual digging.

These notes are merely the record of a preliminary survey and the author believes that work along the lines suggested will lead to results which will be of interest to the world in general and particularly to the world of science.

Acknowledgements. The author wishes to record his sincere thanks to the authorities of the South Australian Museum for providing the opportunity for him to visit Henbury; to Professors Sir Douglas Mawson and Kerr Grant for their enthusiastic support and advice; and to Mr. F. L. Winzor for his invaluable help and company during the stay at the meteorite locality.

Addendum by L. J. Spencer

After reading the typescript of Mr. Alderman's most interesting paper, I was rather surprised to find that the meteorite craters he describes are marked on 'The Times' Atlas (London, 1922, plate 105). Between Henbury and Bacons Range they are indicated as a small round hill in exactly the position shown on Mr. Alderman's sketch-map (fig. 1). The latitude and longitude of the spot are 24°34′ S., 133°10′ E. This is about 50 miles south of the MacDonnell Ranges in the very centre of Australia. After Mr. Alderman's visit to the locality in May 1931, a visit was made in June by the brothers R. and W. Bedford and Mr. B. Duggin from the Kyancutta Museum at Kyancutta, South Australia, which involved a journey by motor truck of about 3000 miles. Of the material then collected Mr. R. Bedford has sent to the British Museum a large series of 542 complete pieces of the meteoric iron ranging in weight from 3·4 grams to 170½ lb. (77½ kg.). There are large pieces weighing 11,445 and 6550 grams and several of about 2 kg., but the majority are small shelly and jagged pieces. The total weight of the 542 pieces is 321 lb. (146 kg.). In addition, about 20 lb. of 'iron-shale' and fused rock fragments were sent; also excellent sketches and photo-

graphs made by Mr. R. Bedford of the craters. The Adelaide party collected 800 pieces of the iron, and the Kyancutta party 550.

It is quite evident that at these craters there was a large shower of many separate masses of meteoric iron. But the presence also of the laminated 'iron-shale' in pieces up to several pounds in weight (the largest piece sent by Mr. R. Bedford weighs 1668 grams) and up to $5\frac{1}{2}$ cm. in thickness indicates that the iron has suffered considerable oxidation by weathering. Many of the smaller pieces of iron are flaky and shell-like with convex and concave surfaces, and they often show fantastically twisted forms. In one or two cases such a shell-like flake is only loosely attached to a larger piece. It therefore seems probable that many of the smaller pieces are the result of the breaking down of larger masses by oxidation.

From my examination of the 60-ton Hoba meteorite (this volume, p. 1), buried in situ with its enveloping zone of 'iron-shale', I am convinced that the concave and pitted surfaces so commonly shown by iron meteorites are the result of subsequent weathering rather than of burning during the brief flight through the atmosphere. This pitting is no doubt due to the decomposition of the particles of troilite (FeS) scattered through the iron. The surface of the Henbury irons, with a skin of glazed limonite, is quite different from that of the few iron meteorites which have been actually observed to fall.

The presence of the 'iron-shale' supports Mr. Alderman's conclusion that the fall of the meteorite took place ages ago. Mr. R. Bedford is, however, of the opinion that the fall is comparatively recent. On his return journey he interviewed, at Oodnadatta, Mr. J. M. Mitchell, a local prospector, who had known of the masses of iron twelve years ago. Mr. Mitchell asserted that the old blacks would not camp within a couple of miles of the place, and that they called it 'chindu chinna waru chingi yabu', meaning 'sun walk fire devil rock'.

An etched section of the iron shows well-marked Widmanstätten figures of the medium octahedrite type. Besides kamacite, taenite, and plessite, there are a few minute specks of troilite. The kamacite bands, instead of being straight, are wavy and in places much curved and distorted. During the process of etching no straight and definite Neumann lines were detected, but the kamacite bands are marked by wavy lines and an irregular net-work of cracks. This would indicate a disruption of the mass, which may have taken place at the time of fall or at some earlier period.

Mr. Alderman's paper is a valuable contribution to the scanty knowledge of the problematical meteorite craters; and in the case he describes the association of meteorites with the craters could scarcely be fortuitous. Meteorite fragments have been also found around the single craters of Cañon Diablo (Arizona) and Odessa (Texas), but none near the craters of Tunguska (Siberia) and Kaali (Esthonia).[1] Around the 60-ton Hoba (South-West Africa), the largest known meteorite, there is no sign of a crater.

Explanation of Plates II and III.

Meteorite craters at Henbury, Central Australia.

Fig. 4. View from the south of craters nos. 6, 7, and 8. The full extent of the Main Crater (no. 7) is hidden by nos. 6 and 8. The larger trees are in the Water Crater (no. 6).

Fig. 5. Panoramic view of the Main Crater (no. 7).

Fig. 6. Inside wall of the Main Crater. Over the edge are seen the tops of the trees in the Water Crater.

Fig. 7. View inside crater no. 12, showing shattered blocks of sandstone in the crater walls.

Fig. 8. Typical fragments of the meteoric iron. (With scale of inches.) $\times \frac{1}{3}$.

[1] Min. Abstr., 1931, vol. 4, pp. 427–428; 1932, vol. 5, pp. 16–17.

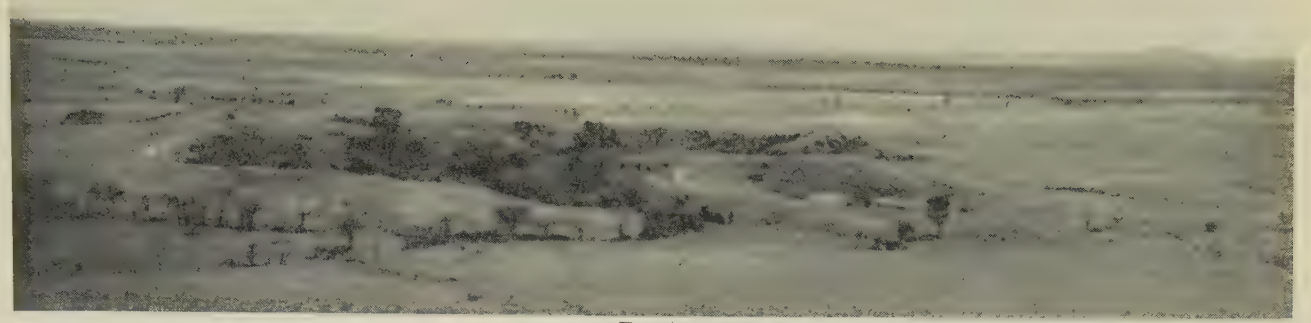

Fig. 4.

Fig. 5.

A. R. Alderman: Meteorite Craters at Henbury, Central Australia.

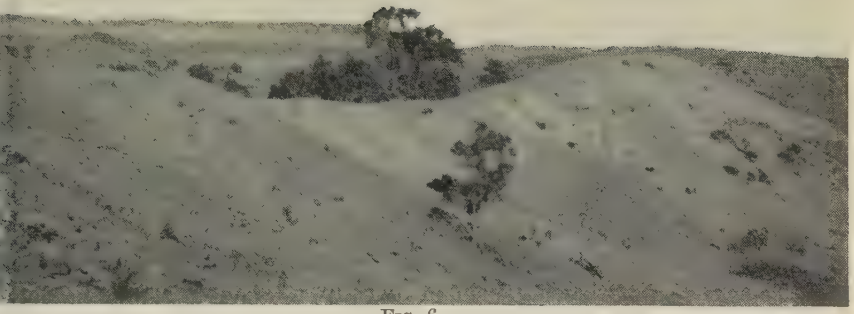

FIG. 6.

FIG. 7.

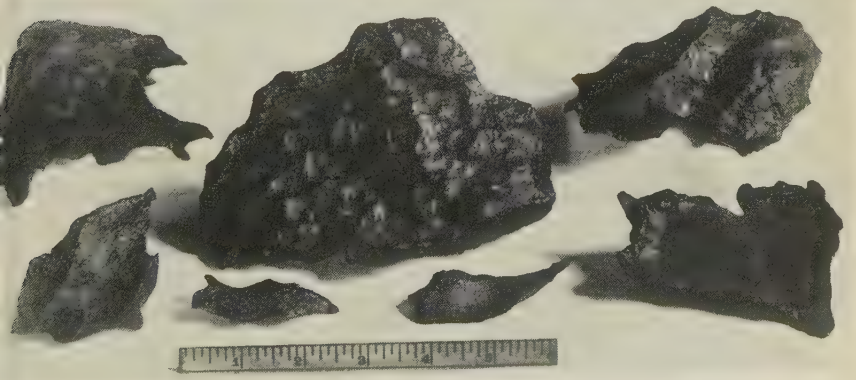

FIG. 8.

A new siderolite from Bencubbin, Western Australia.

By Edward S. Simpson, D.Sc., B.E., F.A.C.I.
Government Mineralogist and Chemist, Western Australia,
and D. G. Murray, A.A.C.I.

[Read November 3, 1931.]

In July 1930 a fragment of this meteorite was received at the Government Laboratory, Perth, with a request from the sender that he should be informed of its nature and value. Realizing its scientific interest, one of the authors (E. S. S.) took advantage of a visit to Bencubbin (lat. 30° 48′ S., long. 117° 51′ E.; about 150 miles NE. of Perth in the South-West Division) to interview the finder and suggest that the whole mass should be handed over to the Government Laboratory for examination, a specimen detached for the British Museum, and the main mass finally presented to the Western Australian Museum in Perth. This arrangement was agreed to.

The mass was found in 1930 almost completely buried in some newly cleared ground on Holland and Breakells wheat farm (Block 2557) situated 12 miles NW. of Bencubbin. The broad base was found projecting to the extent of only two to three inches above the soil.

It is a single complete body weighing 119·5 lb. (54 kg.) and having roughly the form of a square-based frustrum. Its dimensions are 12×8 inches (30×20 cm.) on the base, 7×5 inches (18×13 cm.) on the top, and 9 inches (23 cm.) deep. The whole of the surface is covered by the usual thin oxidized crust. It is not deeply thumb-marked over the greater part of the surface, but there are two deep grooves close to one another, one 4 inches long by 1·5 inch deep (10×4 cm.), the other 3 inches long and 1 inch deep (8×3 cm.). One of these grooves, as well as the general outward appearance of the meteorite, is illustrated in figs. 1 and 2.

When an attempt was made to break off part of the meteorite for distribution and analysis, it was found to be very tough owing to

the skeleton of nickel-iron. A fresh fracture is rough and hackly, with a background of greyish to brownish-black colour, through which are rather regularly distributed a number of masses of a greyish-white silicate. The latter has a density of 3·15 to 3·17 and proves to be enstatite. Each of these masses appears to be composed of a single crystal (often multiply twinned), though sometimes two may

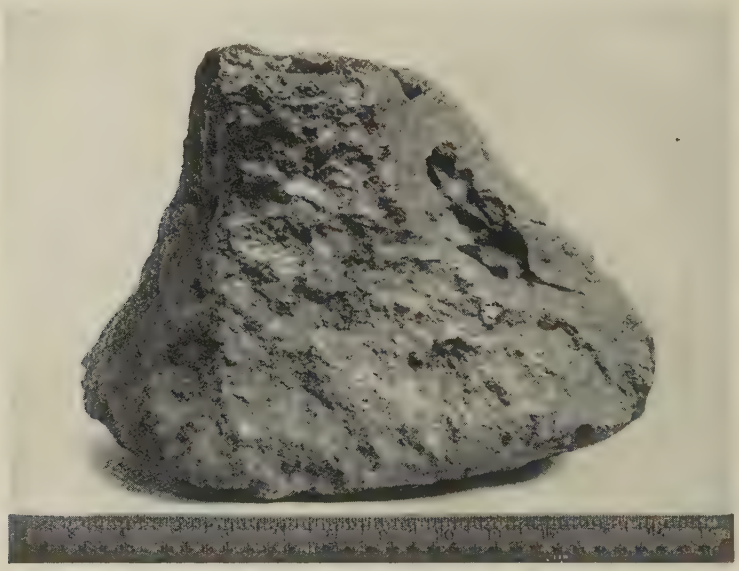

Fig. 1. The Bencubbin meteorite (obverse).
Photograph by B. L. Southern. × 4/15.

be in conjunction. They have subangular to angular outlines, and are usually 5 to 10 mm. (0·2 to 0·4 inch) in diameter. In one place only, a group of small (1 mm. or less) rounded pale grey chondrules are visible. Only very rarely is a fresh metallic fracture seen, the meteorite tending to rupture along the surfaces of the metallic masses, which have a thin rusty surface throughout.

By polishing and etching a surface about 1·5 × 1·2 inches (4 × 3 cm.) the metallic component appears in rounded to angular masses up to 1 cm. in diameter. Etching does not reveal any Widmanstätten figures, but brings out a slight blotchiness in the lustre, and resolves most of the largest masses into somewhat smaller individuals separated by a minute film of rust. Between the larger areas are

much smaller threads and specks of metal, representing the cross-sections of coral-like outgrowths from the main masses.

This polishing and etching reveals the dark olive-coloured olivine in crystal individuals of the same size as the enstatite. They are completely obscured by rust on the roughly fractured surfaces.

The anorthite indicated by the analysis could not be detected

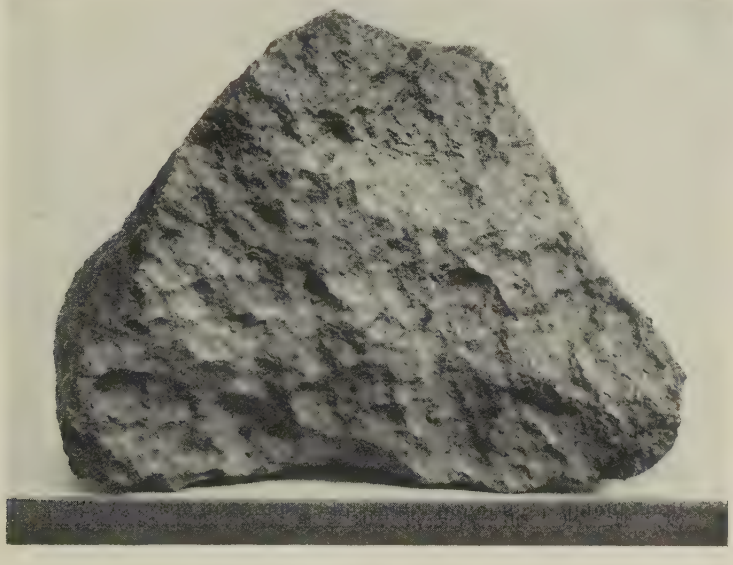

Fig. 2. The Bencubbin meteorite (reverse).
Photograph by B. L. Southern. × 4/15.

macroscopically, and attempts to make a transparent section for examination under the microscope failed, owing to the very coarse grain and the peculiar constitution and state of oxidation of the meteorite.

During the etching the odour of hydrogen sulphide revealed the presence of troilite.

A number of chips of the inner portion of the meteorite weighing in all 30 grams were pounded well in a diamond mortar and sifted, the more metallic portions being further hammered to separate as far as possible the brittle silicates. The broken material thus obtained was separated with a magnet into a magnetic and non-magnetic portion, the finest portions being ground in alcohol and

re-separated by a magnet. The fractions obtained by this treatment were :

Metallics over 10 mesh	46·0 %
,, ,, 30 ,, ...	12·2
,, ,, 90 ,, ...	5·9
,, under 90 ,, ...	6·1
Non-metallic residue	29·8
	100·0

Subsequent analysis of the two fractions, magnetic and non-magnetic, showed that the former still retained about 2 % of silicates, and the latter about the same amount of rusted metal. Analyses made by one of us (D. G. M.) yielded the following results :

Magnetic portion.		Non-magnetic portion.	
Fe*	87·51	SiO_2	47·44
Ni	5·78	TiO_2	0·19
Co	0·63	Cr_2O_3	0·38
S	0·74	Al_2O_3	4·13
Insoluble	0·75	Fe_2O_3	1·10
O, H_2O, sol. SiO_2, and MgO	[4·59]	FeO†	7·06
	100·00	MnO	0·56
		MgO	34·99
		CaO	2·68
		Na_2O	0·10
Fe : Ni = 15·1 : 1		K_2O	nil
MgO : FeO = 8·5± : 1·0		Ni	0·13
MgO+FeO : CaO = 20·1 : 1·0		Co	0·02
		H_2O	2·76
		C	trace
			101·54

* Some of this present as ferric hydroxide.

† Approximate, owing to presence of metallic iron and carbon.

The calculated mineral compositions of the two fractions and of the whole meteorite, omitting the water of hydration, are approximately :

	Metallic.	Non-metallic.	Whole. Weight %	Whole. Vol. %
Nickel-iron ...	98·0	—	68·8	47·8
Troilite	2·0	—	1·4	1·6
Enstatite ...	—	45·3	13·5	23·1
Olivine	—	42·0	12·5	20·2
Anorthite ...	—	12·1	3·6	7·1
Chromite	—	0·6	0·2	0·2
	100·0	100·0	100·0	100·0

Calculated specific gravity 5·42

The specific gravities of five separate fragments ranging from 90 to 250 grams were 5·16, 5·21, 5·24, 5·38, and 5·67. The weighted mean of these is 5·32. This agrees closely with the figure calculated from the analysis in which no allowance was made for the known hydration. It was from these five fragments that the material for the analysis was taken. The specific gravity of the 10 lb. (4533 grams) fragment reserved for the British Museum was slightly less, namely 5·14. Assuming that the other constituents are present in the same relative proportions as in the analysed portion, this represents a content of about 64 % of nickel-iron, the weighted mean specific gravity of the other components being calculated to be 3·23. The highest recorded gravity, 5·67, indicates 74 % of nickel-iron. The distribution of the metal is therefore somewhat uneven, as one would expect in such a coarse-grained mixture.

The Bencubbin meteorite does not closely resemble any other siderolite of which details could be found in the available literature. According to the classification of A. Brezina, as elaborated by G. T. Prior,[1] it would be classed as a mesosiderite, characterized by the presence of hypersthene (or enstatite), olivine, and plagioclase with nickel-iron and troilite, the ratio of nickel to iron being low. The proportion of nickel-iron is much higher than is usual in this group.

[1] G. T. Prior, Min. Mag., 1916, vol. 18, p. 26; 1920, vol. 19, p. 51.

A new pallasite from Alice Springs, Central Australia.

(With Plate IV.)

By L. J. Spencer, M.A., Sc.D., F.R.S.,

With chemical analyses by M. H. Hey, B.A., B.Sc.

Mineral Department, British Museum of Natural History.

[Read January 19, 1932.]

DR. Herbert Basedow of Adelaide generously presented in November 1931 for the British Museum collection of meteorites a pallasite which he had collected in Central Australia in 1924 while leading the Vice-Regal Expedition. During his extensive explorations in Central and Northern Australia it had remained unpacked for some years. He gives the locality as on the Burt Plains, NNE. of Bond Springs in the Alice Springs district; lat. 23° 33′ S., long. 133° 52′ E. This is immediately north of the MacDonnell Ranges and about ten miles north of Alice Springs. The fragment was found lying on the surface and only partly buried in loose ferruginous sand. No doubt other pieces of this material remain to be found in the district.

This locality is about 80 miles NE. of the Henbury meteorite craters (this vol., p. 19) on the south side of the MacDonnell Ranges, but the meteorites from the two places are of quite distinct types. After the thrill of unpacking Mr. R. Bedford's wonderful collection of 542 masses of the Henbury meteoric iron it was a remarkable coincidence that Dr. Basedow should call at the Museum on the very next day with this interesting specimen from the north side of the MacDonnell Ranges. This arid region is evidently especially suitable for the preservation of meteorites that have fallen during past ages.

The specimen is an irregular slabby piece measuring about $11 \times 8 \times 3$ cm. and as received it weighed $1084\frac{1}{2}$ grams. By facing and polishing one surface the weight has been reduced to 1036 grams. The surface shows hackly metal and some flat cleavage

planes up to 1 cm. across of brown olivine, with only a small amount of iron rust. During the preparation of the polished surface by Mr. T. F. Vincent it was noted that the metal was unusually hard to the file. The Henbury iron yielded much more readily.

The polished surface (Plate IV, fig. 2) shows an irregular distribution of nickel-iron and olivine, both of which are present in large amount. The olivine is rather friable, and during the filing it broke out from the surface in the larger areas. Brecciated fragments of olivine, often of minute size, are seen scattered through the iron. An exact measurement of the actual areas occupied by metal and olivine was therefore not attempted. But a series of linear measurements with a millimetre scale gave as a mean result nickel-iron 42 % and olivine 58 % (by volume). The polished surface also shows (but not distinguishable in the photograph) a number of small irregular patches of pale bronze-coloured troilite, which are in most cases situated at the junction of the metal and the olivine, but sometimes as small veins in the kamacite.

Even before etching, the polished surface of the metal shows indications of a coarse granular texture. This is brought out distinctly by etching for a few minutes with very dilute nitric acid. Grains of kamacite up to $\frac{1}{2}$ cm. across have smaller angular areas of plessite in the interspaces, and between the two there is a bright narrow band of taenite (Plate IV, fig. 3). Small angular fragments of olivine are embedded in the kamacite, suggesting that the olivine had been broken up before the kamacite crystallized out. The granular texture of the metal also suggests that the kamacite had been broken up before the separation of the taenite and plessite, and that the fragments had been partly redissolved in the residual melt giving the reaction-rim of taenite. Finally, the plessite eutectic separated out in the interspaces.

Under the microscope, the kamacite shows well-marked Neumann lines in several directions. Kamacite and taenite show a sharp line of separation, and the Neumann lines do not extend into the taenite. Possibly these Neumann lines were developed at the time when the kamacite was broken up. The plessite shows a very fine Widmannstätten structure, and its feathery edges extend into the taenite, there being no sharp line of demarcation between the two.

The specific gravity of the whole mass (1036·125 grams) was determined by hydrostatic weighing as 5·16; that of the lumps of olivine broken out of the cavities as 3·41; and that of the metal

filings separated with a magnet as 7·87. Calculated from these figures the amounts of olivine and nickel-iron are :

	Weight %	Volume %
Olivine	40·2	60·8
Nickel-iron	59·8	39·2

This agrees with the estimate obtained above by linear measurement. Quite different figures were, however, obtained by a magnetic separation of the powder saved when filing down the surface, namely for the attracted portion 70 % and for the unattracted portion 30 % (by weight) ; but this is no doubt accounted for by the loss of some olivine as dust, and, further, some of the olivine is attracted owing to the presence of magnetite.

The olivine in mass is dark brown in colour. Thin splinters under the microscope are almost colourless and quite fresh, but stained with brown iron hydroxide and black oxide along crevices. The following optical data for the olivine have been obtained by Mr. M. H. Hey : α 1·667, β 1·684, γ 1·701, 2V about 90°.

Chemical analyses have been made by Mr. M. H. Hey of the small lumps of olivine and of the filings attracted by a magnet, with the following results :

Olivine.		Nickel-iron alloy.[1]	
SiO_2	37·24	Fe	92·28
TiO_2	nil	Ni	7·27
FeO	16·92	Co	0·20
MgO	43·88	S	0·21
CaO	1·26	P	nil
	99·30		99·96
Sp. gr.	3·41	Sp. gr.	7·87
MgO : FeO (mol.) ...	4·6	Fe : Ni (wt. %) ...	12·7

The bulk composition of the meteorite calculated from these figures and the proportions of olivine (40·2 %) and nickel-iron (59·8 %) is :

Fe.	Ni.	Co.	S.	SiO_2.	FeO.	MgO.	CaO.	Total.
55·35	4·36	0·12	0·13	15·02	6·82	17·69	0·51	100·00

This result compares closely with the composition of the Brahin (Russia) and Brenham (Kansas) pallasites given by P. N. Chirvinsky [2]

[1] The analysis of the nickel-iron was made by the chlorine distillation method described on pp. 13, 48 of this volume.

[2] P. N. Chirvinsky, Pallasites. Bull. Don Polytech. Inst. Novocherkassk, 1918, vol. 6, sect. 2, supplement, 19 pp. (Russian). [Min. Abstr., vol. 2, pp. 83–84.]

in a table of calculated bulk compositions of seventeen pallasites. In his table pallasites are arranged in order of the percentage of olivine, ranging from 37·18 % in Brahin to 75·11 % in Mount Dyrring (New South Wales). Alice Springs therefore lies at the olivine-poorer end of the series of pallasites.

North Australia:

1. Yenberrie, iron, found 1918.
2. Roper River, iron, known before 1927.

Central Australia:

3. Alice Springs, pallasite, found 1924.
4. Henbury, iron, found 1931.
5. Arltunga, iron, found about 1908.
6. Artracoona, iron ?, known before 1927.
7. Cartoonkana, iron ?, known before 1927.

South Australia:

8. Kingoonya, stone, found about 1927.
9. Yardea, iron, found 1875.
10. Carraweena, iron, found before 1927.
11. Murnpeowie, iron, 2520 lb., found 1909.
12. Weekeroo, iron, found 1924.
13. Rhine Villa, iron, found 1900.
14. Cadell, stone, found 1910.
15. Karoonda, stone, fell Nov. 25, 1930.
16. Glen Osborne ?
17. Accalana ?

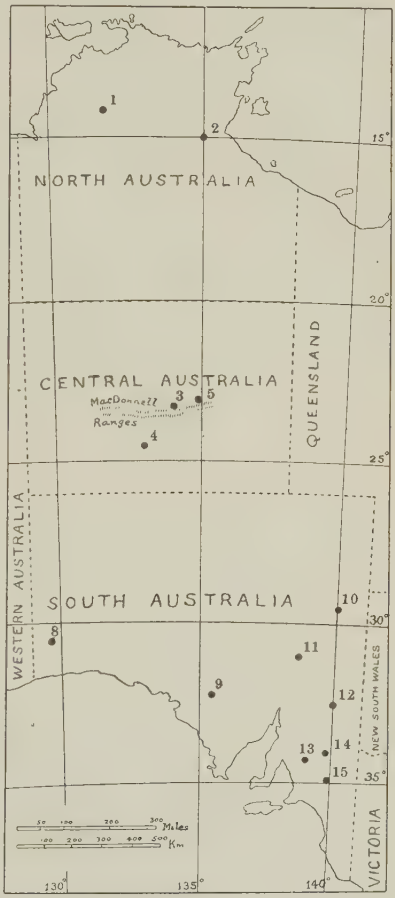

Fig. 1. Sketch-map showing distribution of meteorites in North, Central, and South Australia.

Compared with meteoric stones and irons, the stony-irons or siderolites are the less frequent type of meteorites. Those previously recorded from Australia include: the pallasites 'Australia' (found

1880),[1] Bendock (Victoria, found 1898), Mount Dyrring (New South Wales, found 1903), Molong (New South Wales, found 1912); the doubtful stony-iron of Kulnine (New South Wales, known in 1886); and the mesosiderite of Bencubbin (Western Australia, found 1930).[2]

The accompanying sketch-map (fig. 1) shows the distribution of the meteorites so far known from South Australia, including Northern Territory (North and Central Australia). Several of them are in the South Australian Museum at Adelaide and have not yet been described, and it has not been possible to locate some of these on the map. Of the seventeen listed only one has been observed to fall.

EXPLANATION OF PLATE IV.

Pallasite from Alice Springs, Central Australia.

(Photographs by H. G. Herring.)

FIG. 2. Polished (not etched) surface, showing nickel-iron (white) and olivine (black). Actual size.

FIG. 3. Etched surface, showing the bright band of taenite between the grains of kamacite (white) and the angular areas of plessite (grey). Olivine fragments (black) in the kamacite. In this position (to show the taenite) the Neumann lines in the kamacite are less prominent. The area enlarged is outlined in fig. 2. ×9.

[1] 'Australia' is discredited in G. T. Prior's British Museum Catalogue of Meteorites, Appendix, 1927, p. 9; but it appears in C. Palache's Catalogue of the Harvard Collection of Meteorites, Proc. Amer. Acad. Arts & Sci., 1926, vol. 61, no. 6, p. 152. [Min. Abstr., vol. 3, p. 252.]

[2] E. S. Simpson and D. G. Murray, this vol., p. 33.

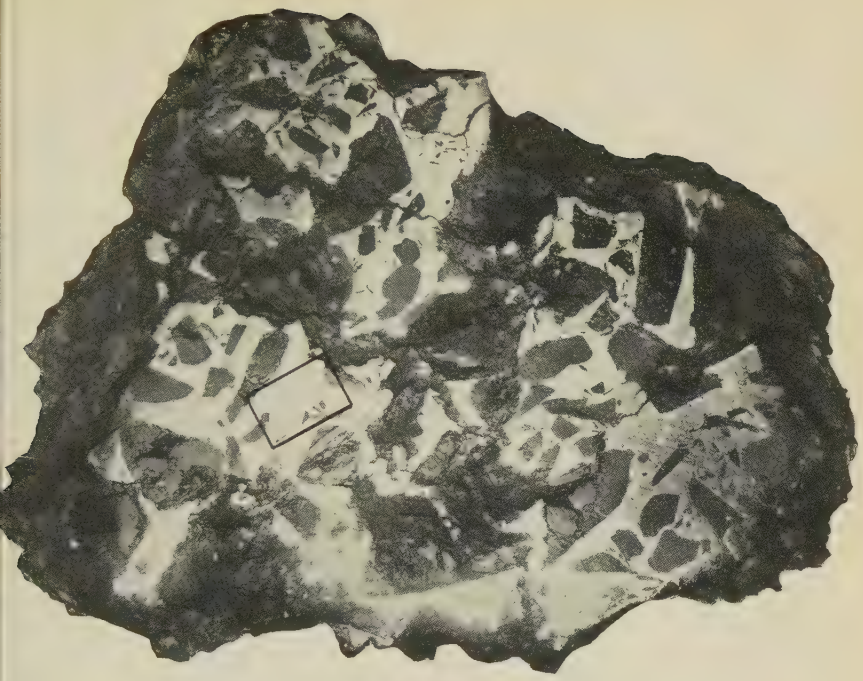

Fig. 2.

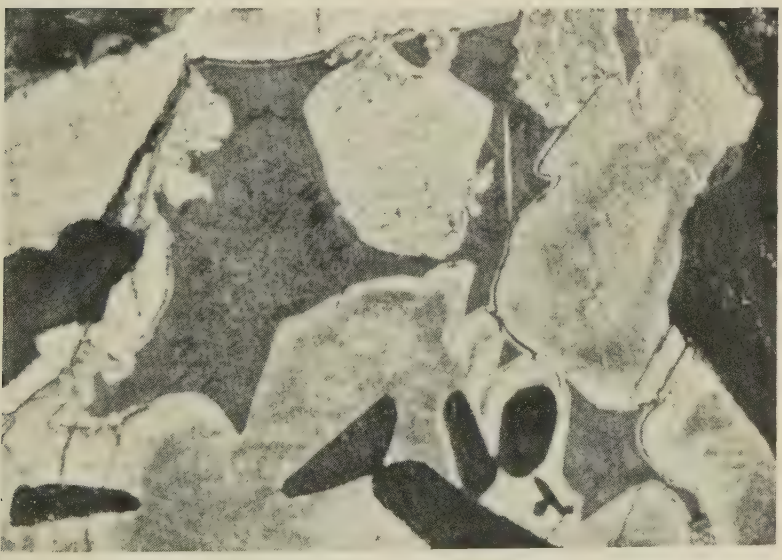

Fig. 3.

L. J. Spencer: Pallasite from Alice Springs, Central Australia.

A new meteoric stone from Suwahib, Arabia.[1]

(With Plate V.)

By W. Campbell Smith, M.C., M.A., F.G.S.
With chemical analyses by M. H. Hey, B.A., B.Sc.
Mineral Department, British Museum of Natural History.

[Read November 3, 1931.]

STARTING in December 1930, Mr. Bertram Thomas made the crossing of the Rub' al Khali, the desert region of Arabia lying between the mountains of the south coast and the Persian Gulf. Never before had this desert been crossed by any European, and probably rarely even by Arabs. The material collected on this expedition has been presented by Mr. Thomas for preservation in the British Museum.

On January 14, 1931, he was at Buwah, in the region of Suwahib (lat. 20° 3′ 20″ N., long. 51° 25′ E.), and near here one of his Arab escort picked up and brought to Mr. Thomas what the latter at once supposed to be a meteoric stone. The Arabs called it 'Guthr al Hadid' meaning 'drop of iron'. No rocks outcrop in the vicinity, and the stone was found lying on the surface of the sand. Mr. Thomas thought that this might indicate that it had fallen rather recently, otherwise sand would have covered it. However, we cannot be sure of this, for in the shifting sands a small solid body might be buried and swept clear again many times. Further evidence that the stone fell some time previous to its discovery is afforded by the coating of limonite which covers the whole stone so effectively that at first the author took the stone to be a piece of 'iron pan'. The coating of limonite is somewhat glazed, presumably by wind action, and grains of sand are firmly cemented in it.

The stone is bounded by seven irregular surfaces, and measures about $8\frac{1}{2} \times 4\frac{1}{2} \times 4$ cm. along three directions at right angles. Only one of the bounding surfaces shows anything resembling the outer crust of a complete stone, and that is doubtful owing to the coating of limonite.

As found the stone weighed 241 grams. A small piece was broken

[1] A preliminary account was given in an appendix to Mr. Thomas's paper, 'A camel journey across the Rub' al Khali', in the Geogr. Journ. London, 1931, vol. 78, p. 236. There the specific gravity is given incorrectly.

off for preliminary examination, and a larger piece for analysis, and preparation of a thin section and of a polished surface for microscopic examination. The weight of the remaining portion of this polished piece is $5\frac{1}{2}$ grams and that of the main portion of the stone 232 grams.

The broken surface shows the characters of a black spherical chondrite traversed by minute veinlets and patches of nickel-iron and troilite. The largest chondrule seen is 1·5 mm. in diameter, but their average diameter is about 0·75 mm. Plate V, fig. 1, from a photograph of the polished surface, magnified 8 diameters, gives a fair idea of the distribution of nickel-iron and troilite, which appear as the lightest patches in the grey mass of chondrules.

The specific gravity of the stone, determined by hydrostatic weighing of the main mass by Mr. M. H. Hey, is 3·52.

Under the microscope the section shows many spherical chondrules consisting mainly of bronzite and olivine, the latter associated with some glass and a plagioclase felspar (Plate V, fig. 2). The bronzite chondrules are fibrous with eccentric radiating structure; some are cryptocrystalline and opaque. The optical properties of the bronzite could not be fully determined.

Chondrules containing olivine are porphyritic for the most part, but several kinds can be distinguished: chondrules consisting of single crystals (monosomatic); idiomorphic crystals of olivine in a granular matrix of olivine or pyroxene; crystals of olivine with interstitial brown glass; and rather rounded crystals of olivine poecilitically enclosed in plagioclase. Measurements made on olivine crystals on the Fedorov stage indicate a value of 2V near 85°, and the optical sign is negative. The acute bisectrix is normal to a good cleavage parallel to *b* (010). There is also a well-marked fracture parallel to *c* (001), and faces in the zone [001,110] are well developed.

The felspar is present in many of the chondrules and is optically positive with a rather low extinction-angle and a refractive index above that of balsam. This would agree with andesine which is the felspar calculated from the analysis. The same mineral appears to form the main mass of a few chondrules, and these contain many opaque inclusions, some of which are troilite.

Troilite within the chondrules is mainly restricted to the outer edges of some olivine chondrules where it is sometimes quite abundant filling interstices between the silicate grains, or forming a very

narrow ring round the chondrule. Much more rarely it forms a sort of lamellar arrangement alternating with one of the silicates (Plate V, fig. 1), but this was not seen in the thin section, so that it could not be decided whether olivine or bronzite was involved.

The interstices between the chondrules are occupied entirely by nickel-iron and troilite, the proportion of the latter being quite considerable. Small pieces of troilite are seen enclosed by nickel-iron, and the two minerals are very closely associated. Occasionally there are seen small chondrules which are completely surrounded by a plate of troilite, but chondrules surrounded by nickel-iron are much more frequent. The troilite is easily distinguished from the nickel-iron in reflected light by its yellower colour. This distinction was kindly confirmed by Dr. W. R. Jones of the Department of Geology, Imperial College of Science, who examined the polished slice in polarized light with a vertical illuminator. On rotating the specimen between crossed nicols the anisotropic character of the troilite was clearly shown and contrasted with the isotropic behaviour of the numerous neighbouring patches of nickel-iron.

No structure was brought out in the nickel-iron by etching with dilute nitric acid.

	Suwahib.	Cronstad.	Hedjaz.
Fe ...	17·54	16·71	12·98
Ni ...	0·96	1·55	0·94
Co ...	0·12	0·23	—
S ...	1·98	Fe 3·29 S 1·88	1·61
P ...	nil	—	—
SiO_2 ...	38·48	37·24	37·30
TiO_2 ...	0·20	0·30	0·05
Al_2O_3 ...	4·42*	2·41	3·78
Cr_2O_3 ...	—	0·37	0·08
FeO† ...	10·16	9·17	11·50
MnO ...	0·28	0·04	trace
NiO ...	—	0·10	—
CaO ...	1·90	1·45	2·95
MgO ...	21·25	23·61	27·50
Na_2O ...	1·33	0·67	0·40
K_2O ...	0·25	0·07	0·50
P_2O_5 ...	n.d.‡	0·25	—
H_2O ...	n.d.‡	0·34	—
	98·87	99·68	99·59
Sp. gr. ...	3·52	3·61	3·53

* Probably includes Cr_2O_3. † Total iron in combination with silicates.

‡ P_2O_5 and H_2O together, 0·6–0·8, by analogy with Cronstad.

The results of a chemical analysis made on a small portion of the stone by Mr. M. H. Hey (using a method which he describes in a note below) are given in the table (p. 45). For comparison are also given the analyses of the Cronstad meteorite[1] and of the Hedjaz meteorite,[2] the latter being the only other stony meteorite that has been described from Arabia.

An analysis of the portion of the silicates (freed from nickel-iron and troilite) soluble in hydrochloric acid (sp. gr. 1·06) gave the following result:

		Calculated percentage composition of olivine.	Molecular ratios.
SiO_2	18·86	37·53 ...	0·622
FeO	12·18	24·24 ...	0·337
MgO	19·21	38·23 ...	0·948
TiO_2	absent	100·00	
Insoluble ...	49·43		
	99·68		

This gives for the ratio MgO : FeO in the olivine 2·81, the composition of the olivine being, therefore, approximately $3Mg_2SiO_4.Fe_2SiO_4$. Assuming this as the composition of the olivine, and allowing 0·5 % of apatite for the undetermined P_2O_5, the mineral composition calculated for the meteorite is as given in the table on p. 47. The calculated mineral composition of the Hedjaz meteorite is given for comparison.

The nickel-iron, 15·15 %, has a ratio of Fe : Ni of 14·7. The ratio of MgO to FeO in the olivine is 3, in the pyroxene 8, in the ferromagnesium silicates taken together 4.

The corresponding figures for the Cronstad meteorite are: nickel-iron 18·5 %, Fe : Ni 11, MgO : FeO in olivine 4, in pyroxene 6, in the ferromagnesium silicates 4·5.

Compared with these figures, and with several others tabulated by Prior (loc. cit., p. 29) for chondrites of the Cronstad type the Fe : Ni ratio for Suwahib, calculated from the bulk analysis, is abnormally high. However, considering the very small quantity of material used for the bulk analysis the figures are sufficiently accurate to show that the Suwahib meteorite, like the Hedjaz stone, belongs to Prior's Cronstad type. The mineralogical constitution and structure of the stone are quite in agreement with this result.

[1] G. T. Prior, Min. Mag., 1916, vol. 18, p. 11.
[2] J. Couyat, Compt. Rend. Acad. Sci. Paris, 1912, vol. 155, p. 916.

The only other meteorites known from Arabia[1] are the famous 'black stone' set in the wall of the Ka'ba at Mecca of which the history goes back beyond the seventh century; a meteoric iron of which two large masses were found in 1863 in the Wadi Bani Khaled in Nejd (Nejed); and a grey bronzite-chondrite which fell in the spring of 1910 at Et Tlahi in the Hedjaz.

Frequent reference has been made above to the Hedjaz meteorite which has been briefly described by J. Couyat and analysed by F. Pisani. That it belongs to the same type as the Suwahib stone is probably nothing more than a coincidence, and it is satisfactory that the chemical analyses show sufficiently considerable differences to allay any suspicion that the two stones might belong to the same fall. This would be most improbable as the two localities are over a thousand miles apart. The differences in mineral composition are quite apparent in thin sections and even in the fragments of the stones themselves, the Hedjaz stone being grey, whereas the Suwahib meteorite is a black spherical chondrite; also the chondrules in the Hedjaz stone as described by Couyat are much larger.

	Suwahib.		Hedjaz.		
$NaAlSi_3O_8$	11·53		3·10		
$KAlSi_3O_8$	1·11	17·9	2·78	13·11	Felspar
$CaAl_2Si_2O_8$ ...	5·28		7·23		
$FeO.TiO_2$		0·3	trace		
$3Ca_3P_2O_8.CaO$ ...		[0·5]	—		Apatite
$CaSiO_3$	1·39		3·13		
$FeSiO_3$	3·17	24·4	2·64	14·47	Pyroxene
$MgSiO_3$	19·80		8·70		
Fe_2SiO_4	11·93		14·30		
Mg_2SiO_4	23·31	35·2	42·00	56·30	Olivine
Fe	3·47		2·79		
S	1·98	5·45	1·61	4·40*	Troilite
Fe	14·07		10·19		
Ni	0·96	15·15	0·94	11·13*	Nickel-iron
Co	0·12		—		
	98·9		99·41		

* The percentages of troilite and nickel-iron in the Hedjaz meteorite as printed in J. Couyat's paper (loc. cit.) were incorrectly given as FeS 11·20 and (Fe,Ni) 4·40. The percentage of nickel-iron was given correctly by G. T. Prior (loc. cit., p. 29), but the ratio Fe : Ni is there given as 9. The calculated value, from Couyat's figures, is 10·8.

[1] E. de Oliveira lists a meteorite [N. 2640] from 'Arabia' in the collection of the Museu Nacional at Rio de Janeiro, Brazil, but he gives no description. (Ann. Acad. Brasileira Sci., 1931, vol. 3, p. 52, and Min. Abstr., 1932, vol. 5, p. 14). This is probably a piece of the Hedjaz stone. A pseudo-meteorite from 'Yafaee Mountains, Arabia' was included in the British Museum lists of 1886 (p. 69) to 1896 (p. 86).

Note on the Method of Analysis by M. H. Hey.

The amount of material available for analysis was very small; it was impossible to take the 10 grams, or more, necessary for a good magnetic separation without spoiling the stone as a specimen, but since the iron is finely divided and very evenly disseminated throughout the mass, it appeared that a sample of 1–2 grams would be sufficient for a fairly complete and representative analysis, provided the difficulty of the complete separation of the nickel-iron alloy from the silicates could be overcome. The method of distillation in chlorine seemed a possibility, and has proved eminently successful.

Preliminary experiments proved that the silicates are quite unaffected by heating to 250–300° C. in dry chlorine, provided that hydrogen chloride is absent; the latter, as F. W. Clarke has shown, is capable of attacking silicates. But if the chlorine is free from hydrogen chloride, and dry, there is no attack. A quantity of olivine from the Alice Springs pallasite showed no change in weight, nor did any portion become water-soluble, when heated in chlorine. As a further test, a partial analysis was made of the non-magnetic portion of the Cronstad meteorite, using the material previously separated and analysed by Dr. G. T. Prior.[1] The troilite present is, of course, attacked, both iron and sulphur distilling; the amount of sulphur found in the distillate (2·25 %) agrees exactly with Dr. Prior's figure, but the iron (5·06 %) is 1·12 % in excess of that needed to combine the sulphur. The residue gave off 0·10 % of nickel on extraction with water, but nothing else. That the silicates were really unaffected is shown by the results obtained on digestion of the residue from the distillation with hydrochloric acid of sp. gr. 1·06, followed by extraction of the liberated silica with sodium carbonate solution; 51·67 % (on the total unattracted, including troilite) remained insoluble, while 15·75 % of silica was liberated; Dr. Prior's figures are 54·78 % and 14·85 %, a good agreement considering the approximate nature of the process.

The excess of iron in the distillate beyond that required to form troilite comes undoubtedly from a small amount of nickel-iron alloy left in the unattracted material. A small loss of this kind is t be expected, and it is significant in confirmation of this that the 0·10 % of nickel left as chloride in the residue after distillation is in almost exactly the correct ratio to the excess of iron in the distillate to be

[1] G. T. Prior, Min. Mag., 1916, vol. 18, p. 10.

accounted for in this way. The calculated amount of nickel would be 0·11 %; and Dr. Prior found 0·13 % nickel oxide in the unattracted portion. It is therefore probable that the greater part of the nickel shown in the analyses of the non-magnetic portion of most meteorites is derived from a small residue of nickel-iron alloy in the material.

The preliminary experiments proving so satisfactory, the method was adopted for the analysis of the Suwahib meteorite. A fragment was crushed and finely powdered, with particular care to avoid loss, and the whole (1·5 gram) weighed into a porcelain boat, placed in a glass tube connected with a pair of trap flasks containing water, and heated to 250–300° C. in dry chlorine free from hydrogen chloride. It must be emphasized that whereas in the analysis of silicate-free nickel-iron the presence of hydrogen chloride is a distinct advantage and renders a small amount of moisture quite harmless, both hydrogen chloride and water must be carefully removed when meteoric stones are under examination. The chlorine is best generated from manganese dioxide or other oxidizing agent and aqueous hydrochloric acid, the gas washed through water and then thoroughly dried.

After two hours, the distillation was apparently complete, the boat was withdrawn (from the end of the distillation tube by which the chlorine stream enters), its contents stirred with a glass rod, and returned to the chlorine stream for a further half-hour. Then the boat was removed, cooled, and weighed. The distillate in tubes and flasks was washed out into a measuring flask, a trace of ferric oxide formed being dissolved with hydrochloric acid, and the tubes well rinsed; iron, sulphur, and phosphorus were determined in the usual way on aliquot parts of this solution. The residue in the boat was extracted rapidly with warm water containing a few drops of dilute hydrochloric acid, filtered quickly on a glass filter-crucible, well washed with hot water, dried at 100° C., and weighed. The filtrates were analysed for nickel and cobalt. The silicates on the filter-crucible were thoroughly mixed with a platinum spatula, and divided into three portions. The major portion, 0·8 gram, was fused with sodium carbonate and analysed in the ordinary way for SiO_2, TiO_2, Al_2O_3, FeO, CaO, and MgO. A second portion of 0·3 gram was used for an alkali determination by the Lawrence Smith method, and on the residue from the water extraction, manganous oxide was determined. For this purpose the residue was dissolved in hydrochloric acid, and filtered from silica; the filtrate was evaporated down with sulphuric acid, cooled, diluted, and filtered from the bulk of the calcium

sulphate, then manganese determined by the colorimetric periodate method. The third portion, 0·2 gram, was digested with hydrochloric acid, sp. gr. 1·06, for two hours on the water-bath, filtered, and the filtrate analysed for SiO_2, FeO, CaO, MgO, and TiO_2 in the usual manner. The dissolved material (together with a certain amount of silica left with the insoluble silicates, and recovered by extraction with sodium carbonate solution) gives, as usual, the composition of the olivine of the meteorite. The quantity of material was insufficient for the determination of phosphoric acid or water.

This new process is not intended to supplant the magnetic separation, but to supplement it. The effect of the chlorination on the minor constituents has not yet been determined, the present experiments only going to show that olivine and pyroxene are not affected. Until the behaviour of the minor constituents to reagents has been investigated, no chemical method of separation can replace the magnetic for investigations in which it is desired to take account of them.

Explanation of Plate V.

Meteoric stone from Suwahib, Arabia.

Fig. 1. Portion of a polished surface taken in reflected light. ×8. The lightest patches are nickel-iron and troilite. Near the top on the right is a chondrule consisting of lamellae of troilite and olivine or bronzite. (Photograph by H. G. Herring.)

Fig. 2. Photomicrograph of thin section. ×39. Showing two fibrous bronzite chondrules and several porphyritic chondrules with idiomorphic olivines. The black areas consist of nickel-iron and troilite. (Photomicrograph by F. N. Ashcroft.)

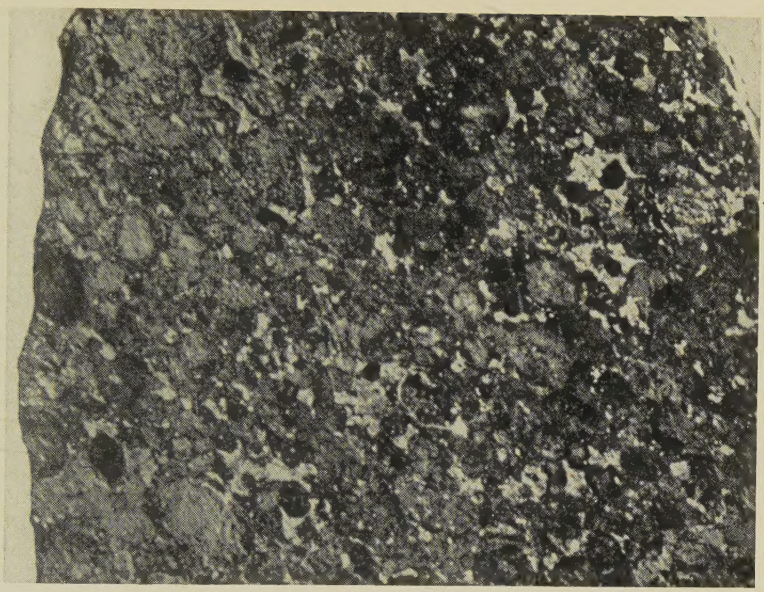

Fig. 1.

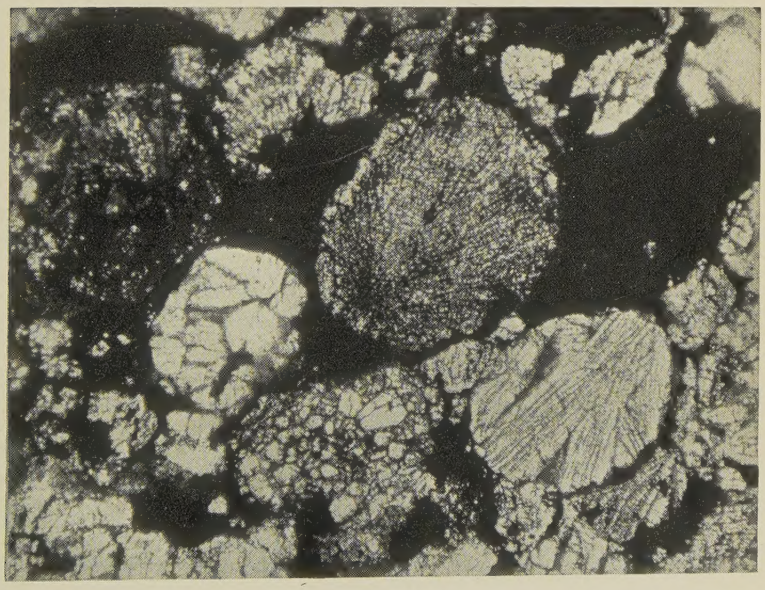

Fig. 2.

W. Campbell Smith: Meteoric Stone from Suwahib, Arabia.